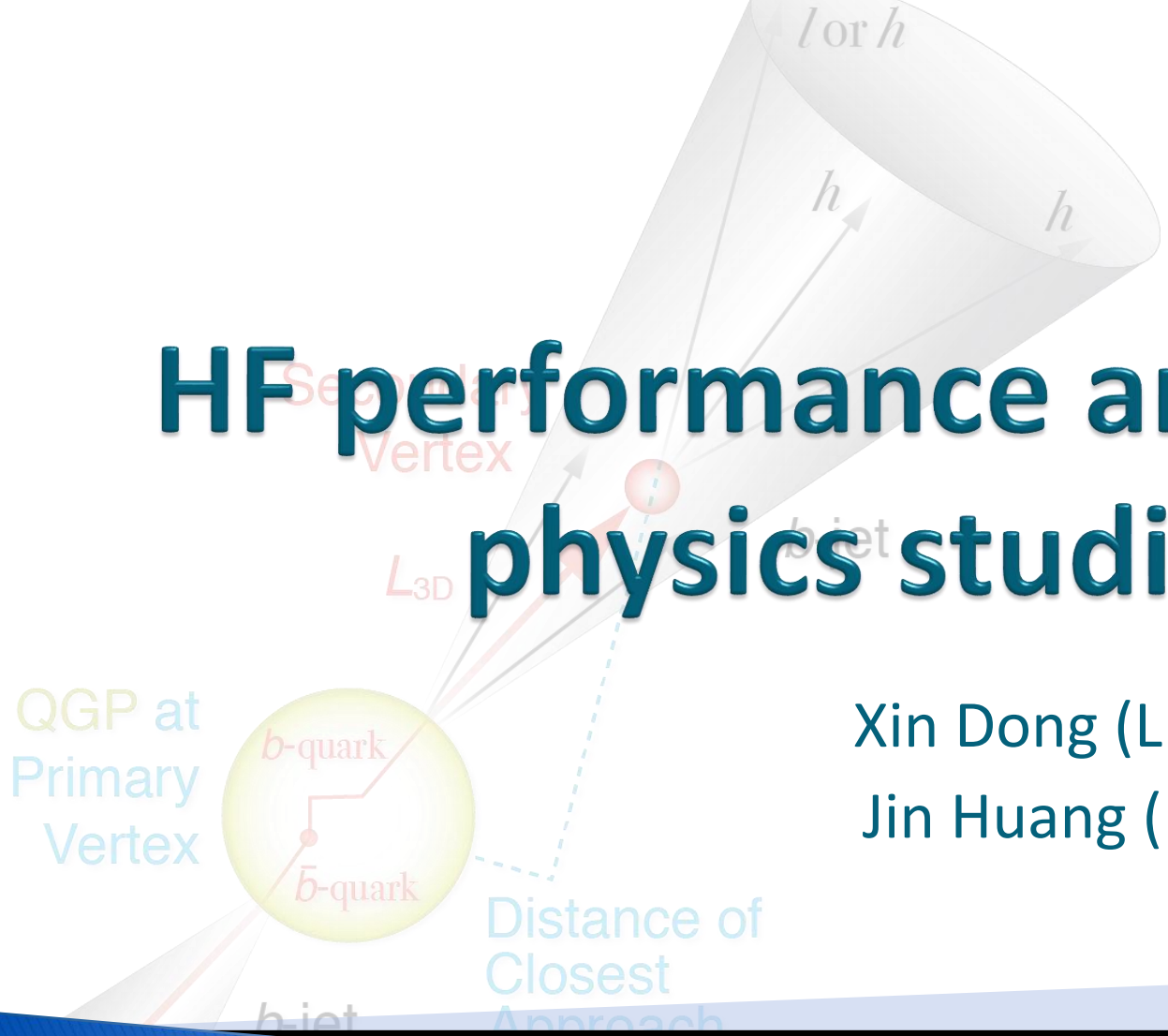


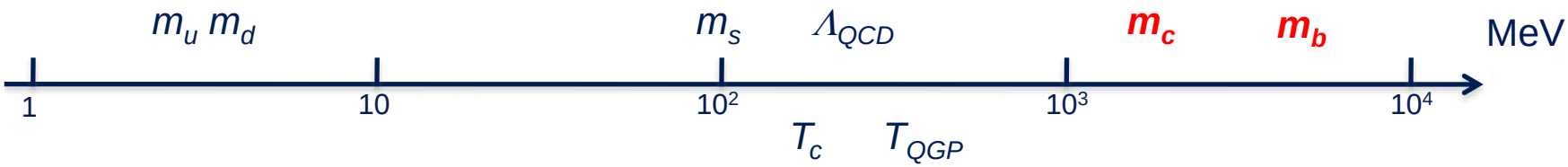
HF performance and physics studies

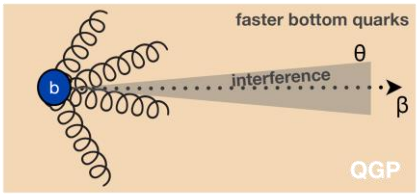
Xin Dong (LBNL)

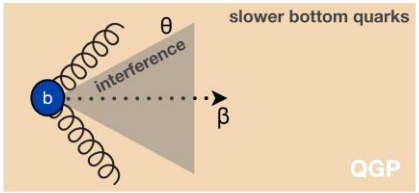
Jin Huang (BNL)

PHENIX

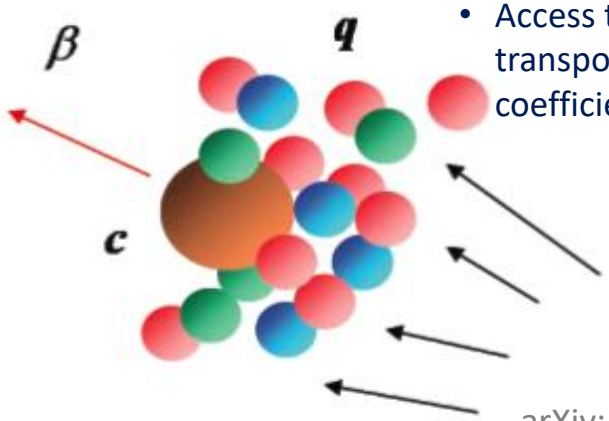
Uniqueness of Heavy Quarks in QCD



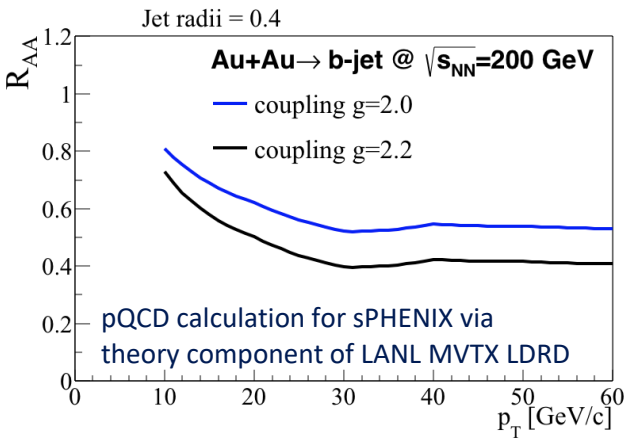


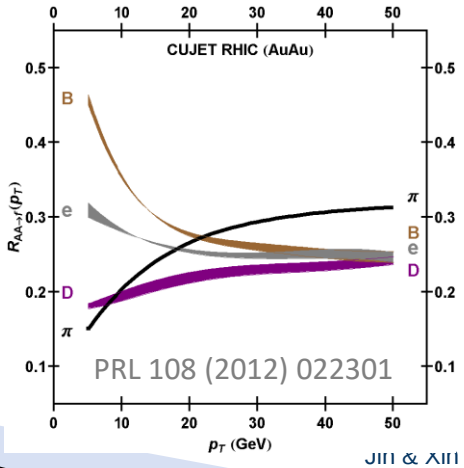


- differentiating sensitivity to collision VS
- radiative energy loss

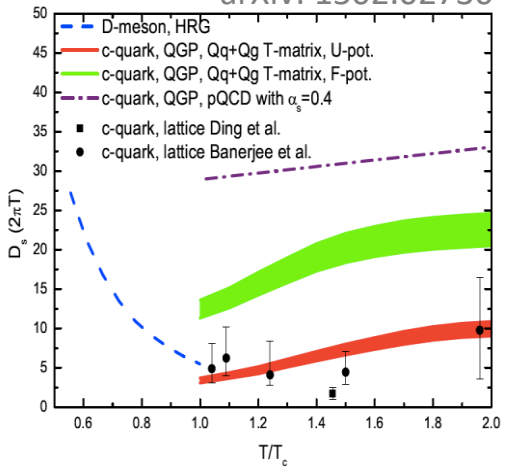


- Access the medium transport, such as diffusion coefficient D_{HQ}



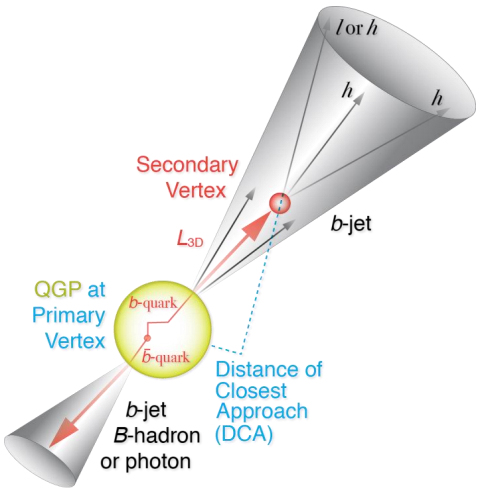


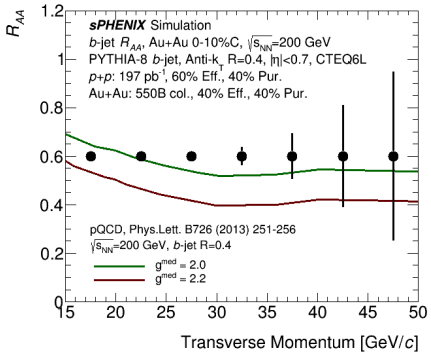
arXiv: 1502.02730

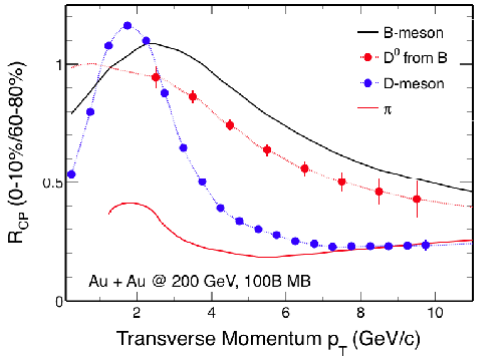


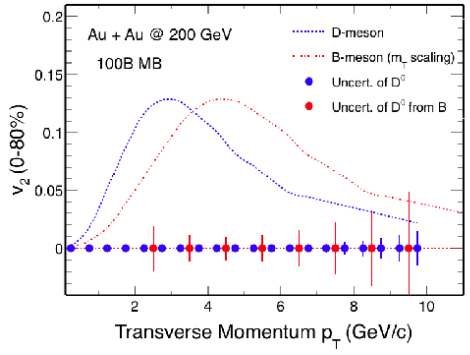
HF-topical group

- HF in sPHENIX: in particular B-meson and b-jets, provide differentiating sensitivity to collision VS radiative energy loss, access to HQ transport parameter of QGP, total cross section. Bring results to precision era.
  - $0<p_T<15$ GeV/c - *B*-meson: access down to zero pT, max sensitivity to HQ mass effect
  - $p_T>15$ GeV/c - *b*-Jet: less dependence on FF complication, probing parton kinematics and higher p_T-scale
- High priority task are set to develop and simulate performance for coming MVTX reviews and proposals, expanding the program in HF-jet and HF-meson programs







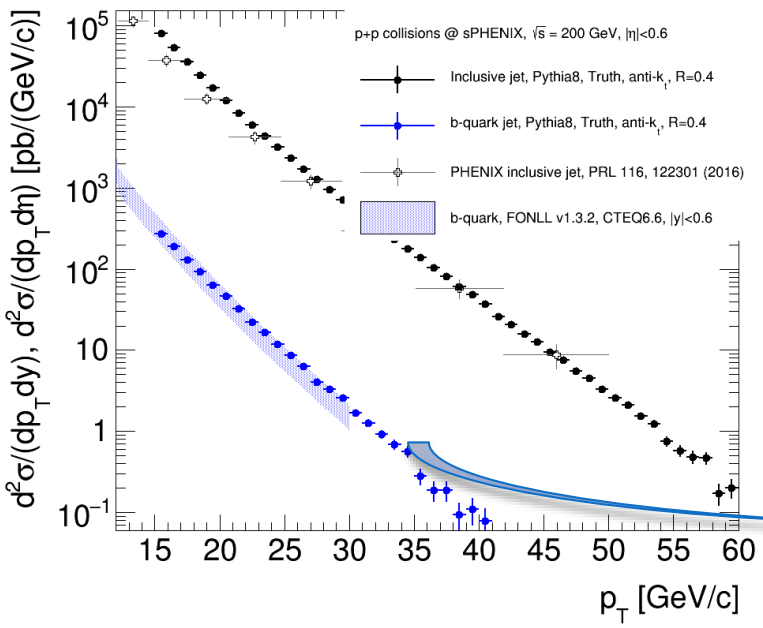


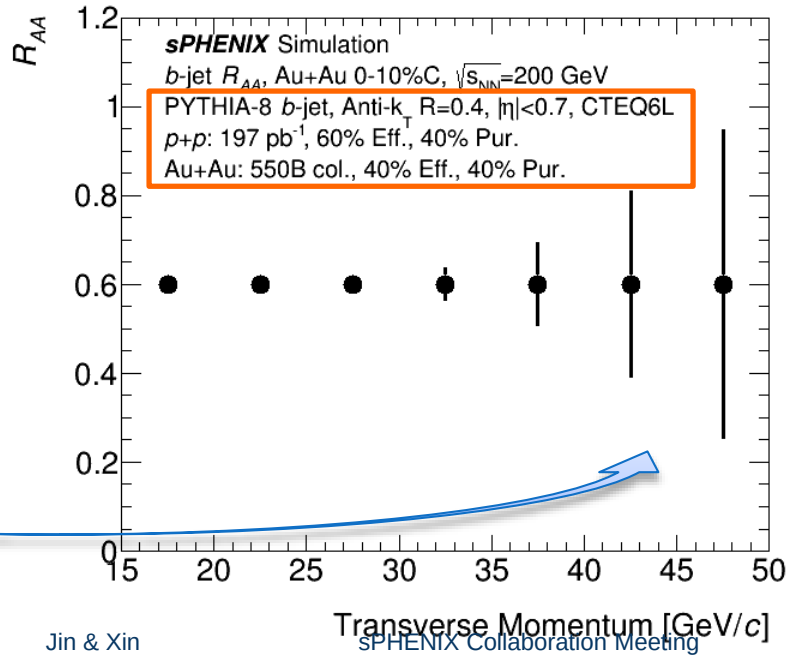
- Communication:
  - Discussion email list: https://lists.bnl.gov/mailman/listinfo/sphenix-hf-jets-l
  - Wiki page under construction: https://wiki.bnl.gov/sPHENIX/index.php/Heavy_Flavor_Topical_Group
- Meetings/Events
  - Use weekly simulation meetings for updates, https://indico.bnl.gov/categoryDisplay.py?categId=88
  - Monthly TG meetings: https://indico.bnl.gov/categoryDisplay.py?categId=151
  - Goal oriented irregular events:

    MVTX brainstorming meeting, Mar 8 / MAPS+HF-jet joint workfests, e.g. Jan 5-7 2017 @ Santa Fe / Pre-collaboration meeting work-fest on May 16-17, 2016 / Initial TG meeting on Apr 22 , 2016

Jet flavor definition and projection

- Unifying truth definition and jet sample generations, based on Dennis' work defining a truth tagging module run on MB events to synchronize *B*-jet definition and yield between analyzers
- PYTHIA8 Hard QCD + CTEQ6L simulation as baseline, motivated by check with LHC/FONNL/RHIC data
  - Need to cross check with NLO generators
- Two options provided in defining truth jet by matching *b*-quark in jet (Default, CMS definition) or by matching *B*-hadron in jet (proposal definition)
- Assuming ***jet-triggered*** |z|<10cm AuAu luminosity of 550B MB col. in 5-year run plan [Jamie's talk]
- Available on GitHub: https://github.com/sPHENIX-Collaboration/analysis/tree/master/HF-Jet/TruthGeneration

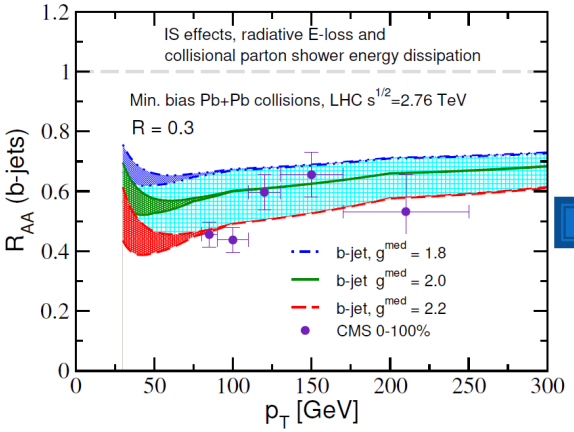


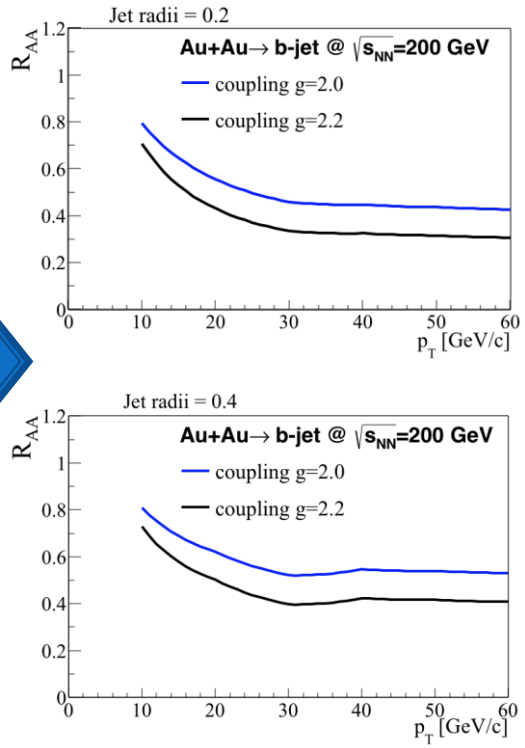


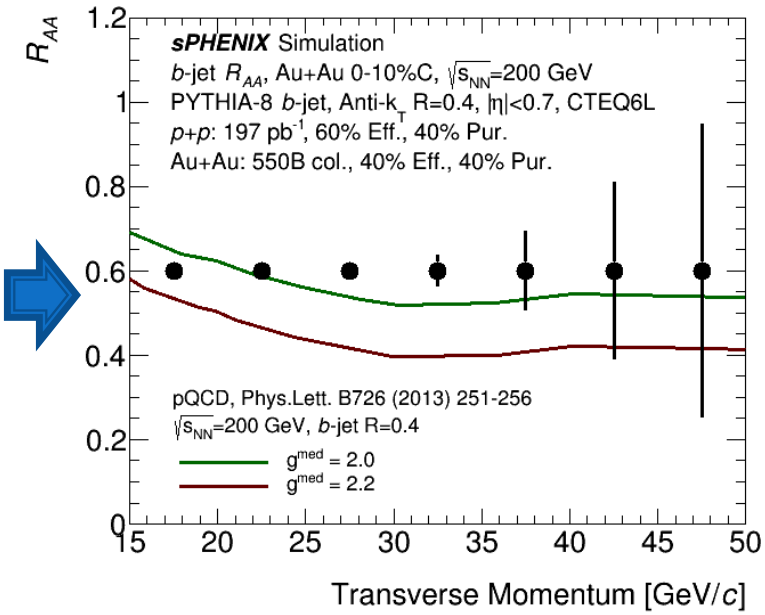
b-jet theory updates for sPHENIX

Cesar da Silva (LANL) working with Ivan Vitev's group updating pQCD calculation of [Phys.Lett. B726 (2013) 251-256] to sPHENIX kinematics

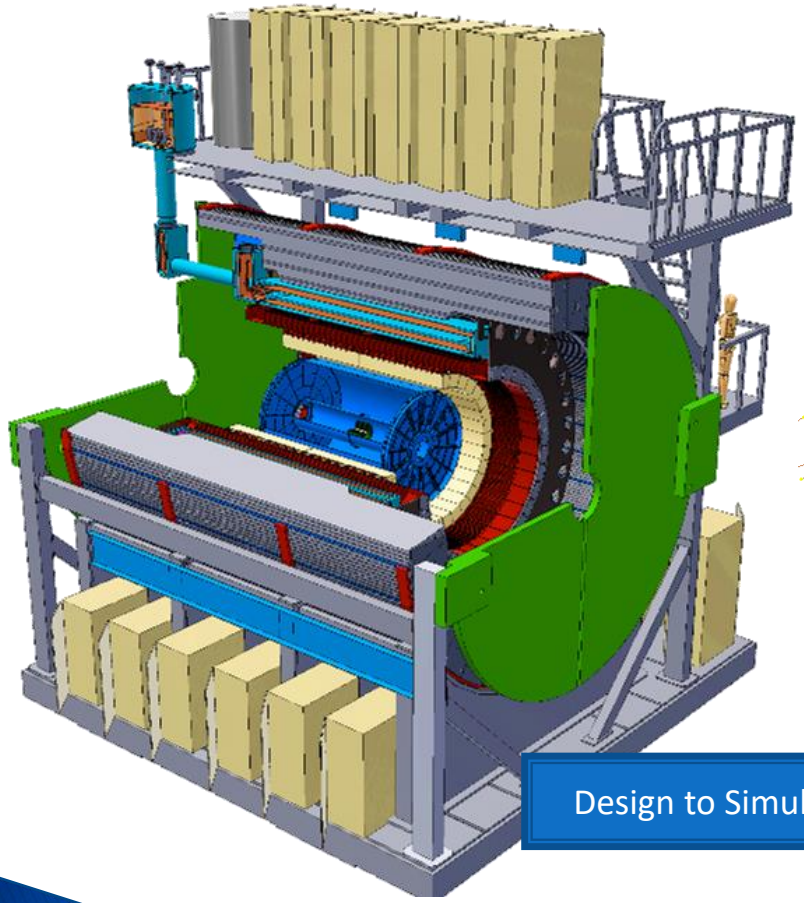
Phys. Lett. B726 (2013) 251-256
Phys.Rev.Lett. 113 (2014) no.13, 132301





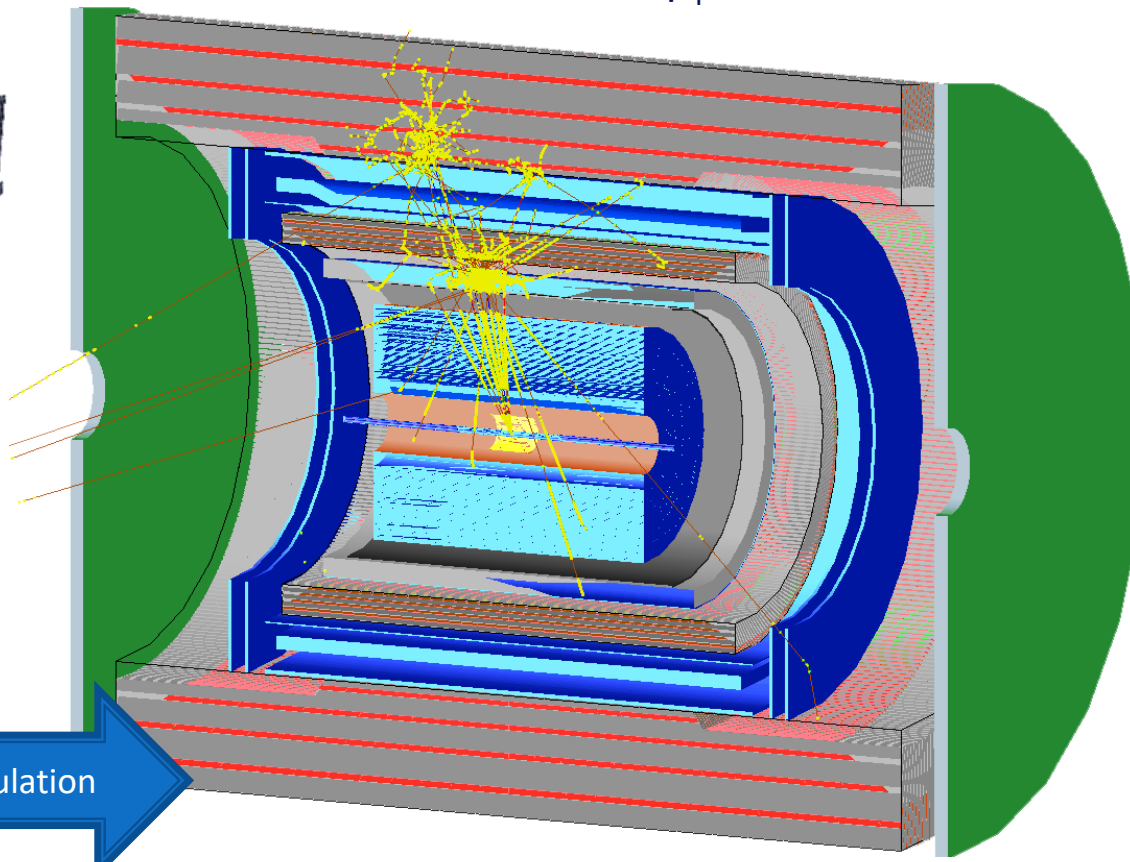


Hunt for b-jet in sPHENIX



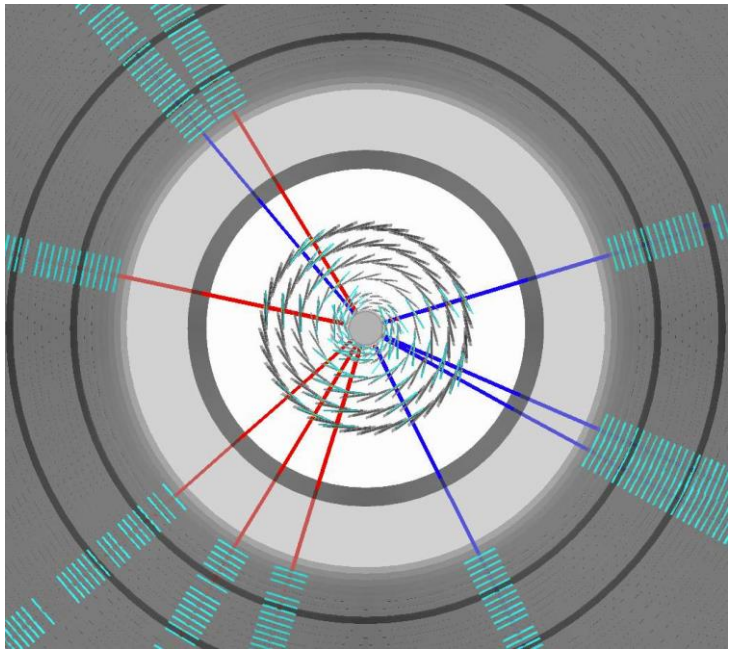
Design to Simulation

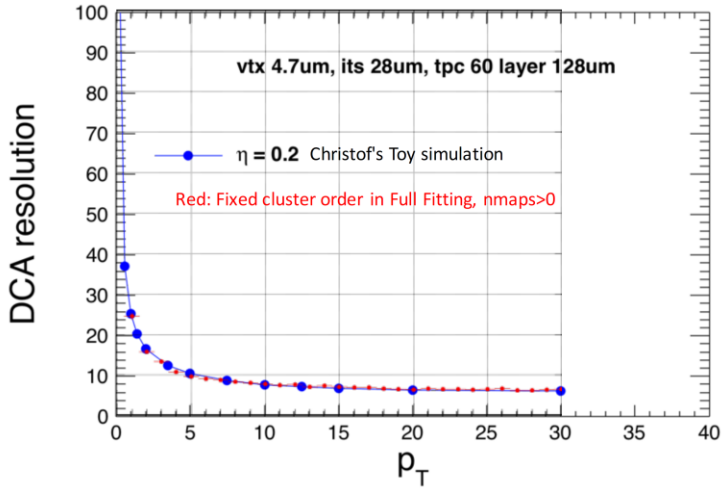
sPHENIX Geant4 simulation of p_T=30 GeV/c B^+-hadron

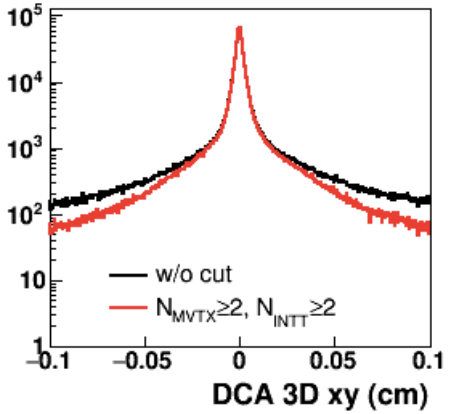


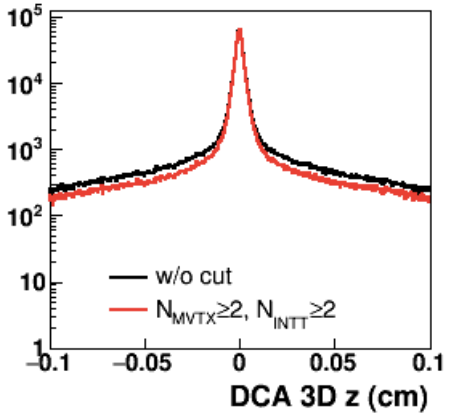
Strong connection to tracking dev.

- Many appreciation of the hard work of tracking team [see Tony's talk]
- Strong connection in analyzers and tracking developers
- Focus from HF topical group:
  - Efficiency down to ~1 GeV/c
    - multi-track displaced vertex
  - Low fake DCA tail
    - rare signal of HF decay
  - DCA resolution
    - differentiate of HF decay



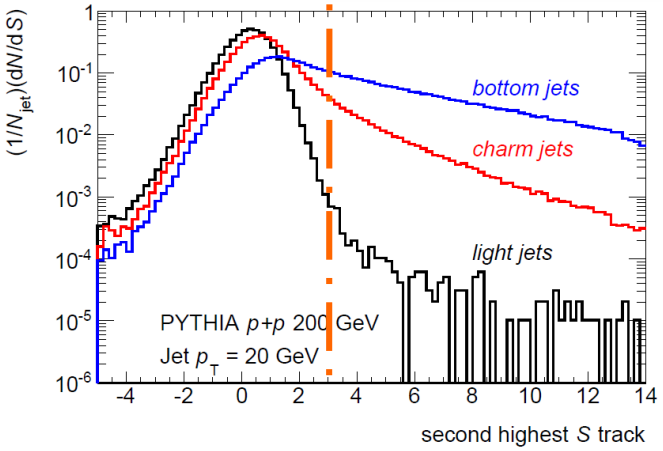




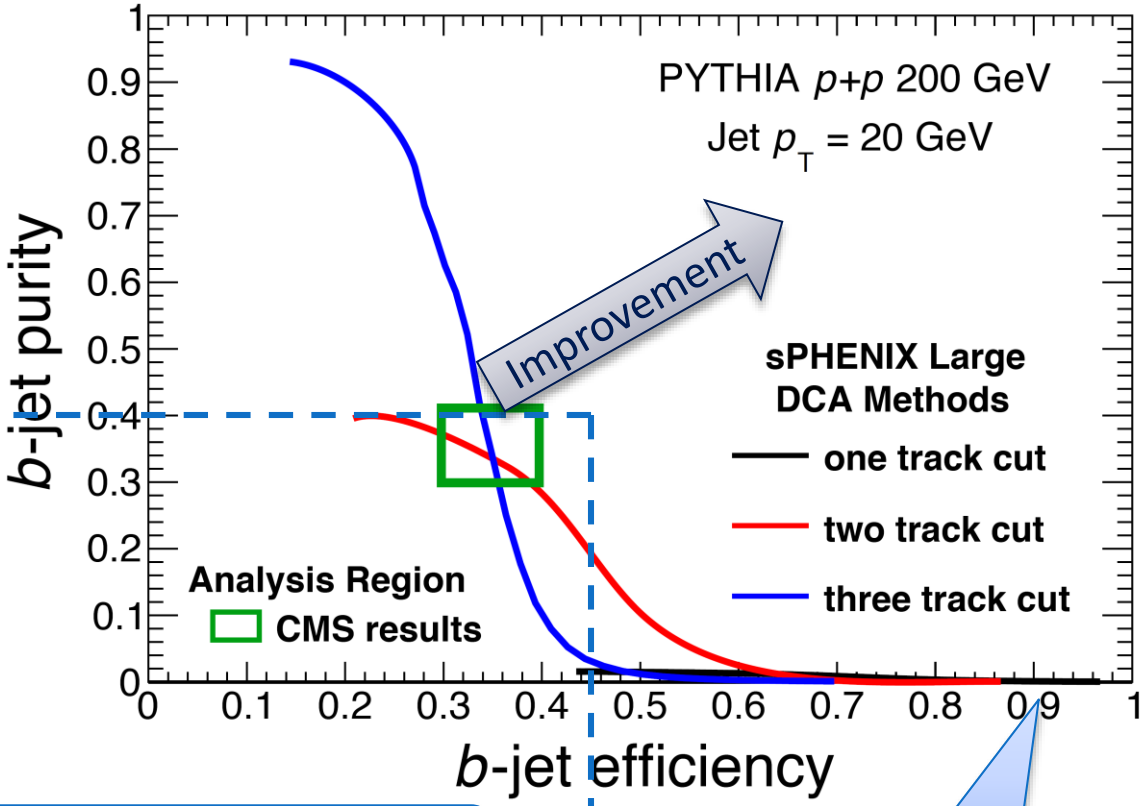


Important factors in b-jet tagging

Cut



sPHENIX-proposal projection based on fast sim.
(already updated to Geant4 simulation)



Saturate efficiency at level determined by

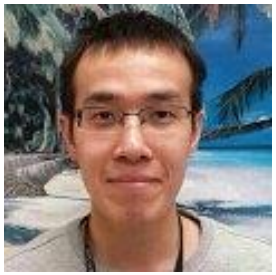
- Control light decay-background
- Fake high DCA (mismatching, alignment) → realistic sim.

Performance turn-on at primary particle's DCA peak
Efficiency improve w/ higher DCA precision and tracking eff.

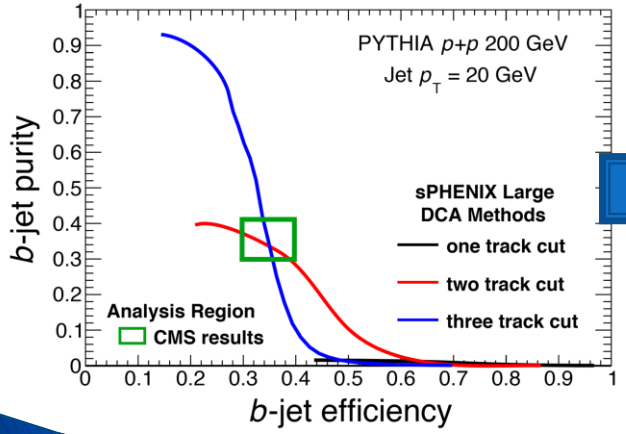
Initial b-jet fraction

Past activities:
b-jet tagging – High DCA track counting

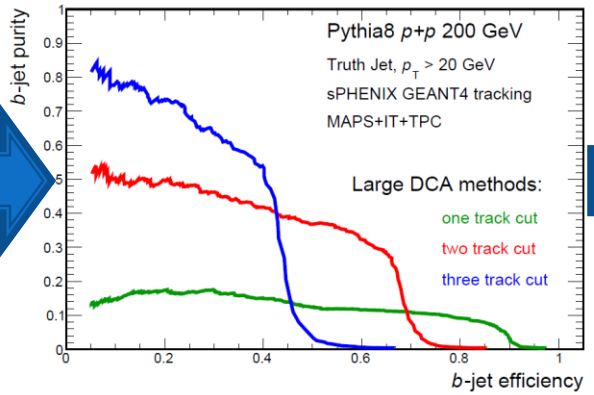
- Short history
  - Dennis and Haiwang implemented track counting tagger in the full Geant4 simulation
  - Haiwang produced projection plot in Geant4 simulation.
  - Systematically validating the Geant4-based track fit procedure, in order to optimize 3-D DCA and likelihood
  - Reevaluate in HI background with HIJING embedding
- Next
  - Use new tracking simulation and pattern recognition



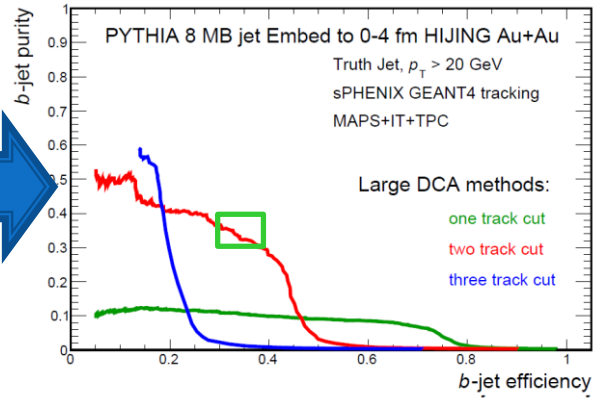
Fast sim in sPHENIX Proposal



Full Geant4 Sim: p+p



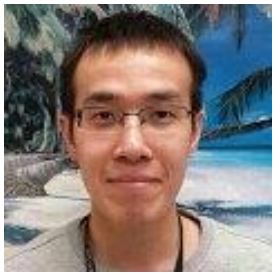
Embedded to Central AuAu



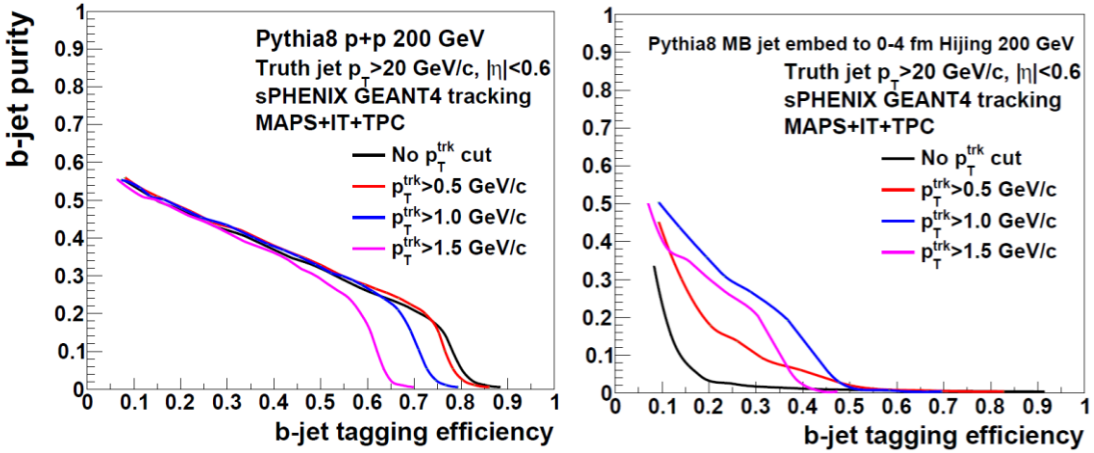
From Haiwang's talk
https://indico.bnl.gov/conferenceDisplay.py?confId=1926

Past activities:
b-jet tagging – Secondary vertex

- Short history
  - Haiwang developed new Kalman filter (GenFit2) with vertex finder integration (RAVE)
  - Sanghoon implemented Secondary vertex finder in jet
  - *p+p* performance plot used in tracking review
- Next:
  - Use new tracking simulation and pattern recognition

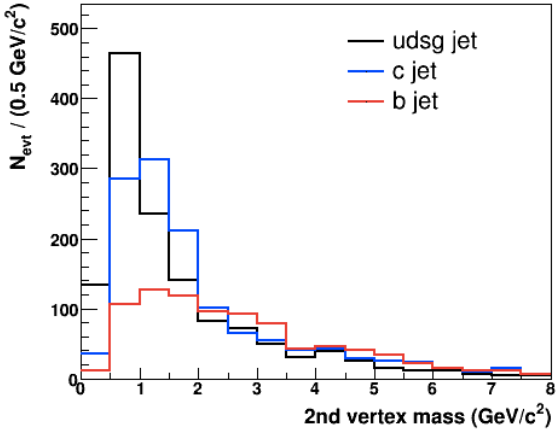


Secondary vertex *b*-tagger



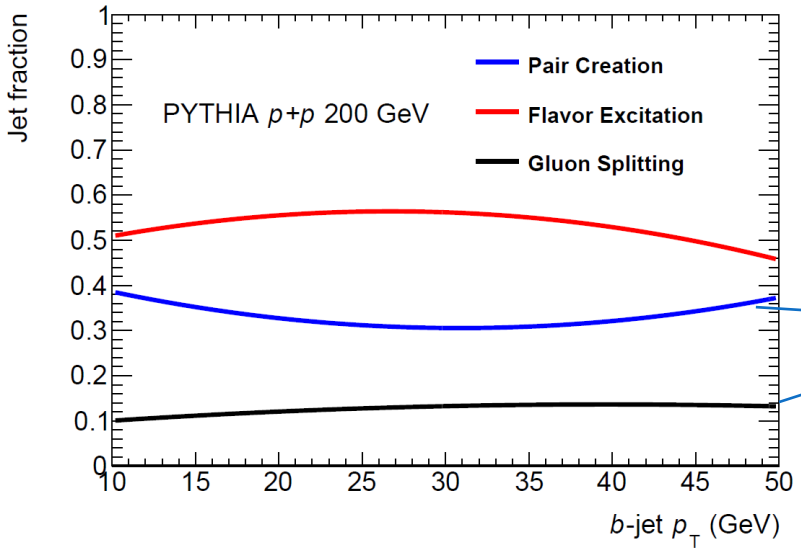
From Sanghoon's talk
https://indico.bnl.gov/conferenceDisplay.py?confId=1928

Secondary vertex kinematics fits
Data driven *b*-jet purity estimation

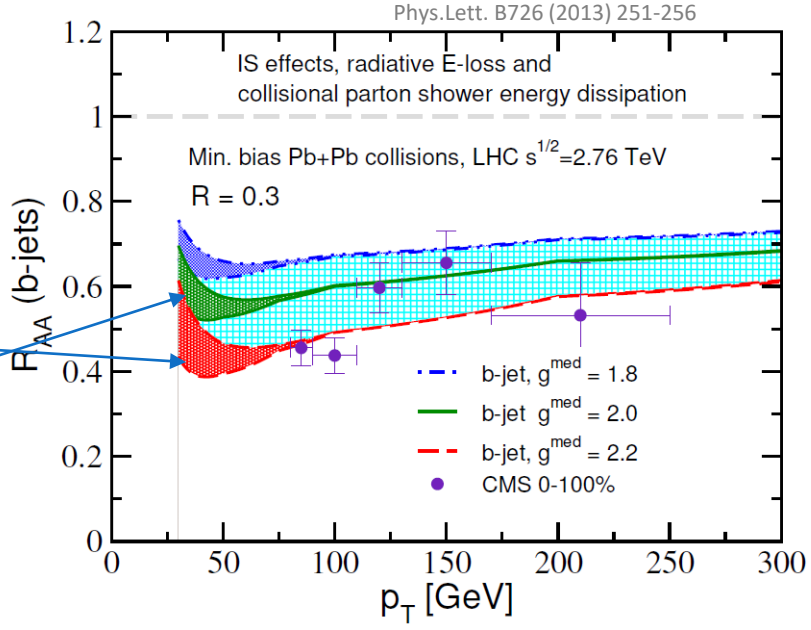


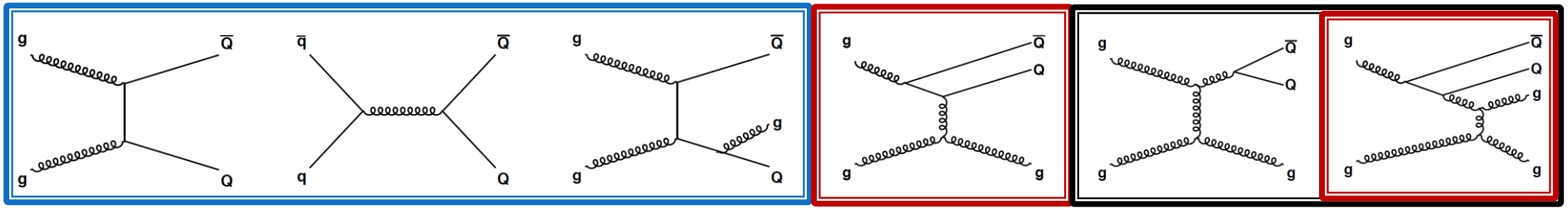
An vulnerability (opportunity) of HF-probes

sPHENIX scientific proposal



CMS, Phys.Rev.Lett. 113 (2014)
Phys.Lett. B726 (2013) 251-256

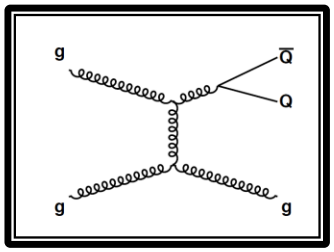


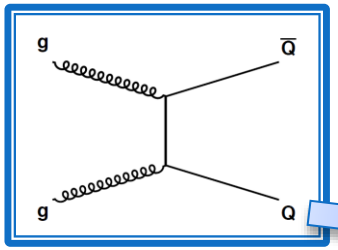


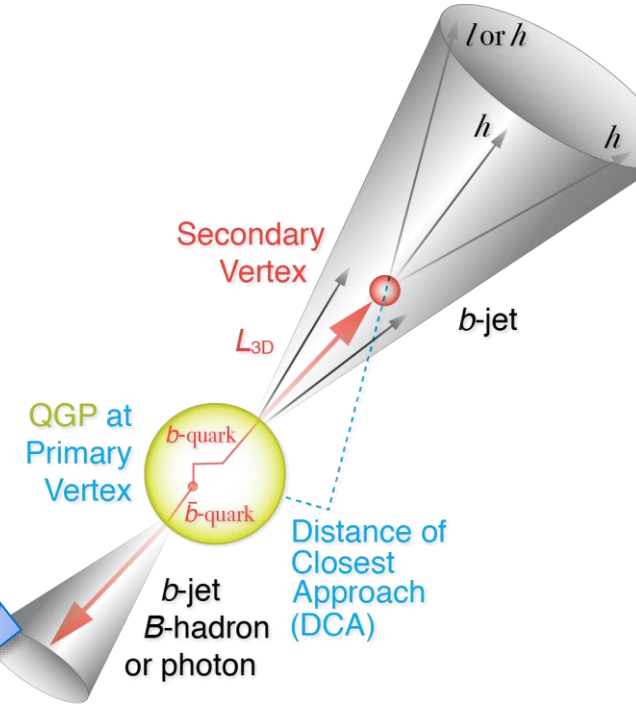
Lund String, Eur. Phys. J. C 17, 137–161 (2000)

b-quark jet selection: *b*-jet correlation

- Event topology to select *b*-quark jet
  - *b*-jet in correlation with opposite-going *B*-hadron, *b*-jet and photon
- sPHENIX provides good acceptance on *b-di*-jet and *b*-jet – non-prompt-*D* correlations
- Helps on purity of jet and *b*-tagging too

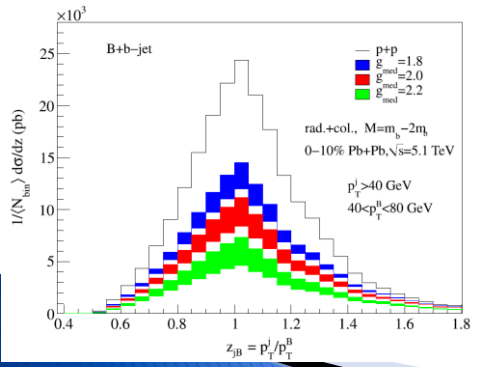






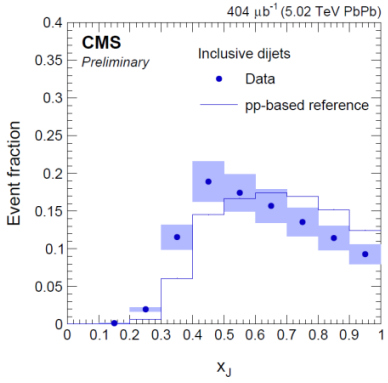
b-jet + *B*-hadron, model

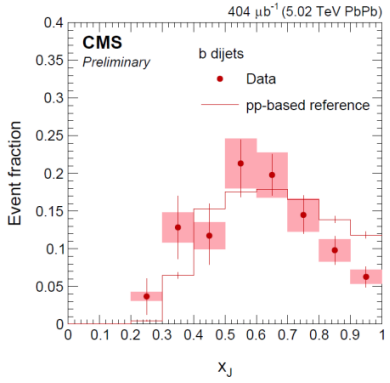
Physics Letters B750 (2015) 287–293



b di-jet, CMS 2016

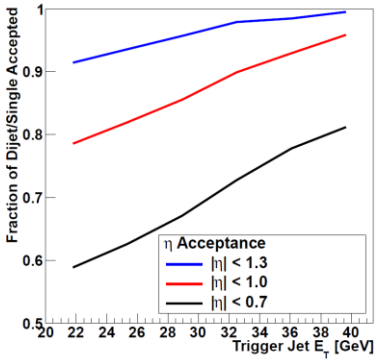
CMS PAS HIN-16-005



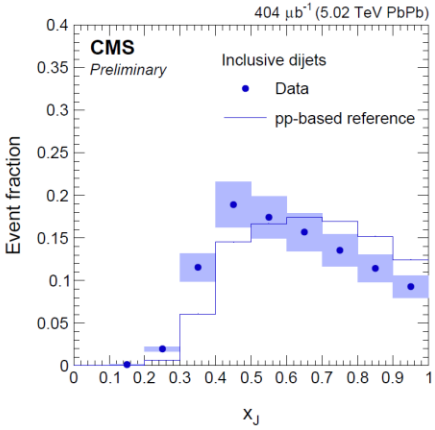


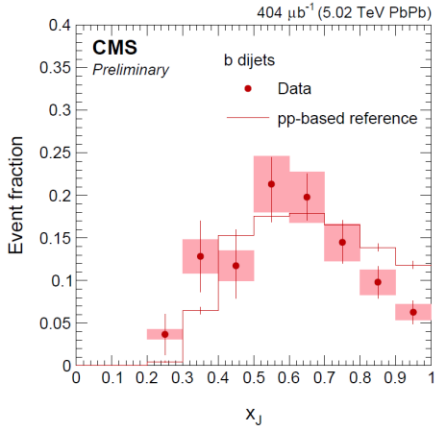
di-jet acceptance in sPHENIX

sPHENIX scientific proposal



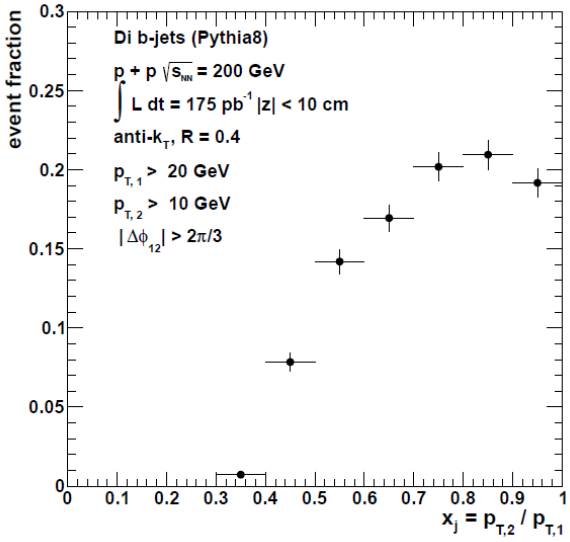
Di-*b*-jet asymmetry: sPHENIX projection

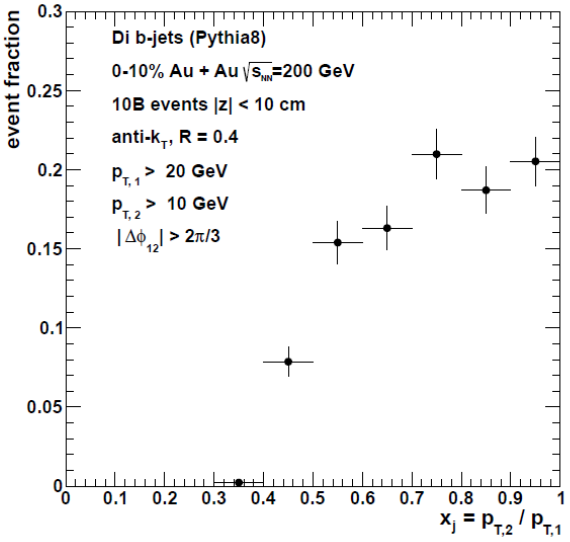




CMS-HIN-16-005

On-going sPHENIX projection
- By Darren McGlinchey (UCB)
- Pythia8 (HardQCDBBar)
- Fast sim. (truth jets)
- Assuming di-b-jet tagging perf.
  - Efficiency 50%
  - High purity (100%)
- R_{AA} = 0.6 assumed
- sPHENIX proposal lumi. (100B MB)



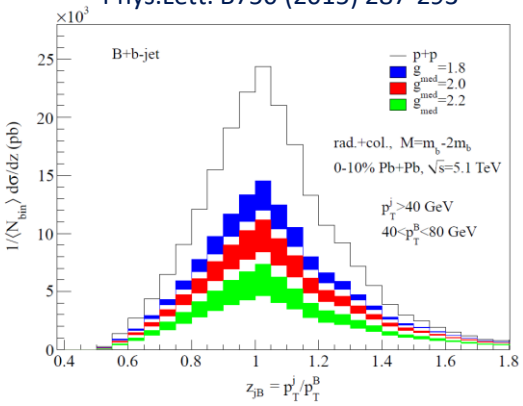


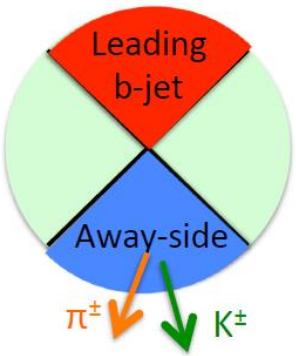
- For $p+p$ use integrated luminosity of $\int \mathcal{L}_{pp}\, dt = 175\ \mathrm{pb}^{-1}$
- For 0-10% Au+Au use $n+n$ equivilent luminosity of $\int \mathcal{L}_{nn}\, dt = N_{evt}^{AuAu} * \langle N_{coll} \rangle / \sigma_{nn} = 10\mathrm{B} \times 962/42\mathrm{mb} = 229\ \mathrm{pb}^{-1}$

Hadron – b-jet balance

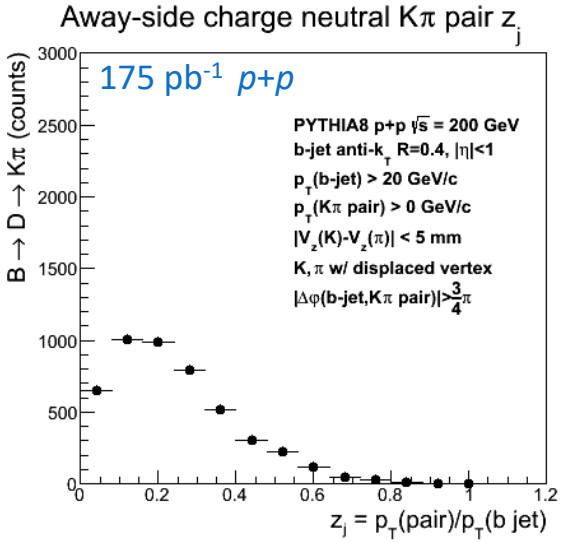
- Xuan Li (LANL) also started investigation of correlation of b-jet in correlation of a non-prompt D_0-meson (→pi + K)
- Goal: tag initial quark energy + vector for non-prompt D measurements, probe b-quark energy loss and fragmentation; access to lower z_j cut-off comparing to di-b-jets correlation; help purity of b-quark-jet tagging

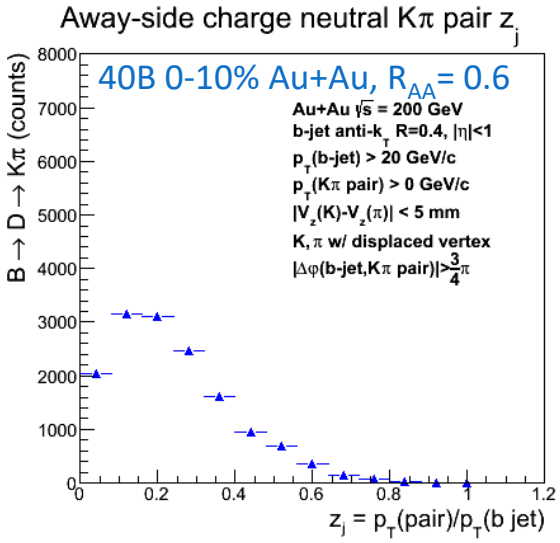
Phys.Lett. B750 (2015) 287-293





Updates in simulation meetings:
https://indico.bnl.gov/conferenceDisplay.py?confId=2684

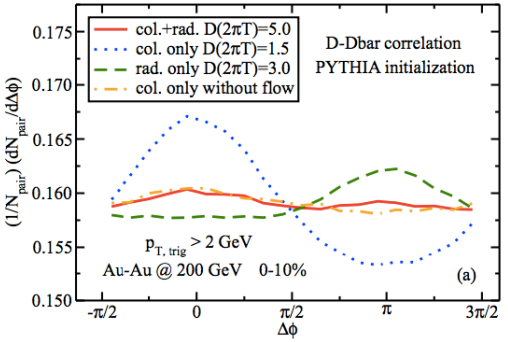


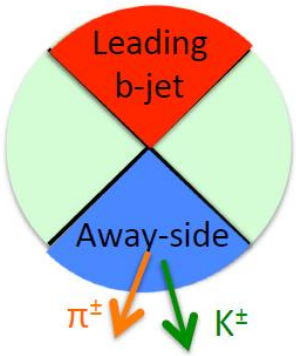


Hadron – b-jet balance: Angular correlations

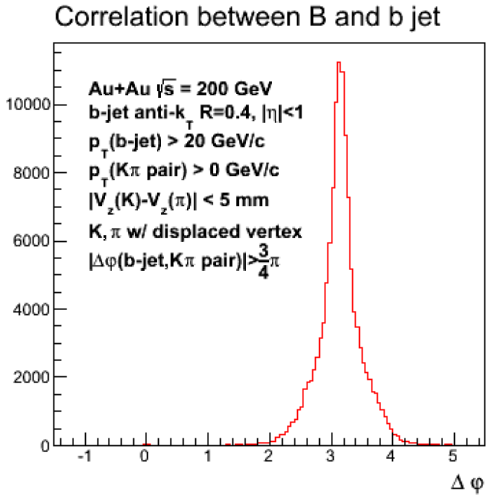
- Xuan Li (LANL) also started investigation of correlation of b-jet in correlation of a non-prompt D_0-meson (→pi + K)
- Goal: tag initial quark energy + vector for non-prompt D measurements, probe b-quark energy loss and fragmentation; access to lower z_j cut-off comparing to di-b-jets correlation; help purity of b-quark-jet tagging

Transport model calculations (D-meson)
S.S.Cao et al, PRC 92 (2015) 054905

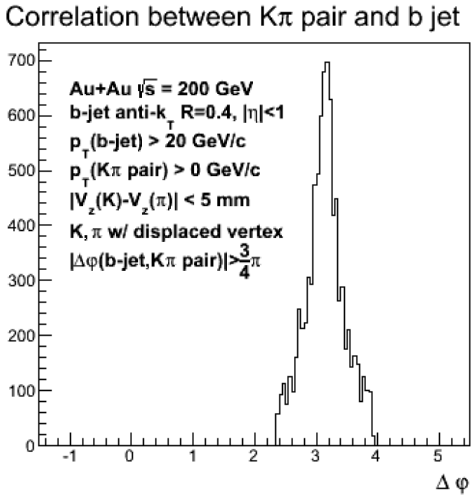




(Not observed)



(Observable)

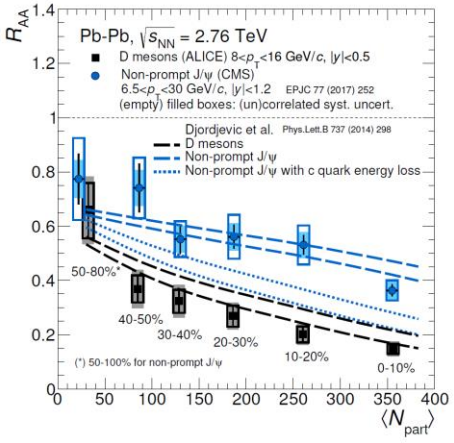


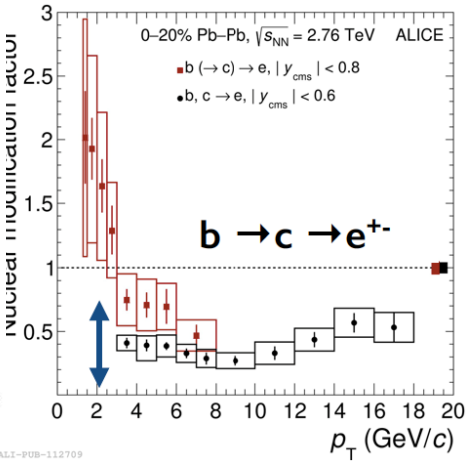
Updates in simulation meetings:
https://indico.bnl.gov/conferenceDisplay.py?confId=2684

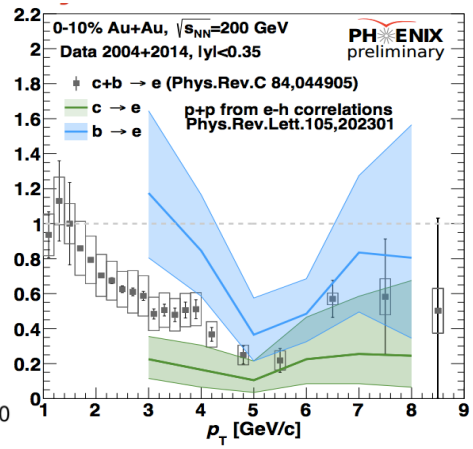
Pythia distribution scaled to stat. of
40B 0-10% Au+Au events, Eff_{Jet}=0.5, Eff_D=0.6

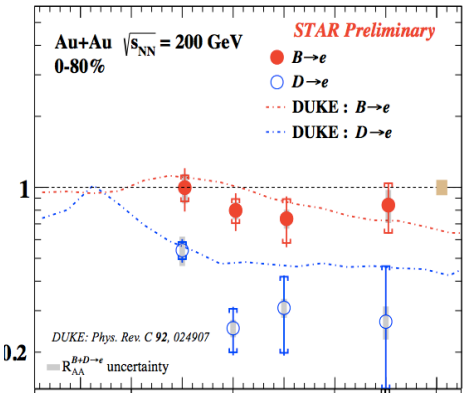
Lower p_T and stronger mass effect – B-mesons, how does sPHENIX contribute?

$R_{AA}(J/\psi_B) > R_{AA}(c\text{-eloss})$ $R_{AA}(e_B) > R_{AA}(e_{D+B})$ @ LHC $R_{AA}(e_B) > R_{AA}(e_D)$ @ RHIC

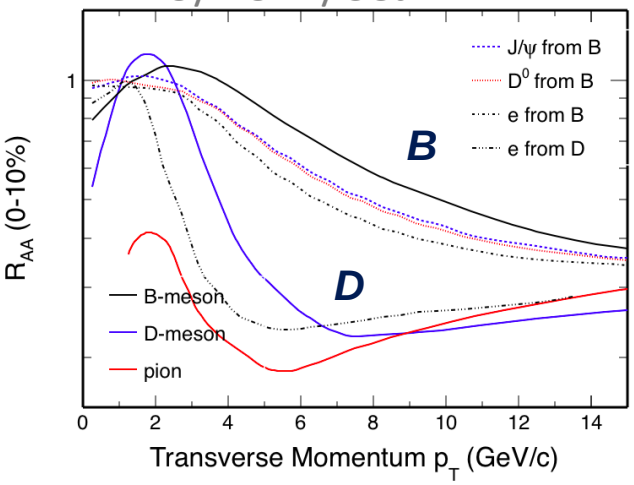








TAMU/DUKE/CUJET

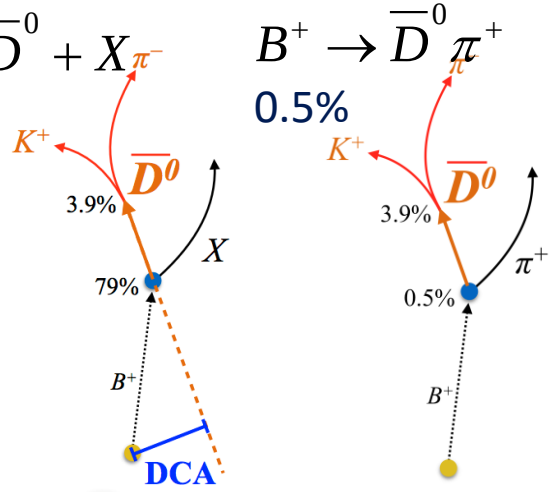


First approaches:

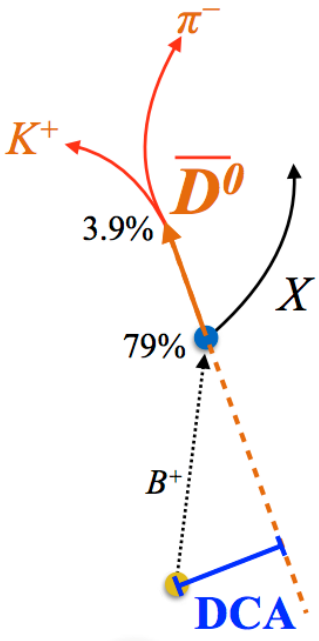
- Golden channel is decay + topological reconstruction of non-prompt D^0, complemented by exclusive channels
- Accessing energy loss via R_{CP}, avoiding triggering req. in pp
- Flow of b-quark via non-prompt D flow, clean access to medium transport than charmed mesons

$B \to \overline{D}^0 + X\pi^-$ 60%

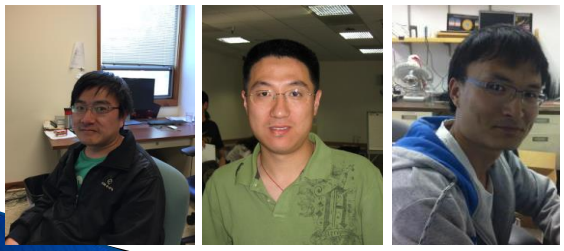
$B^+ \to \overline{D}^0\pi^+$ 0.5%

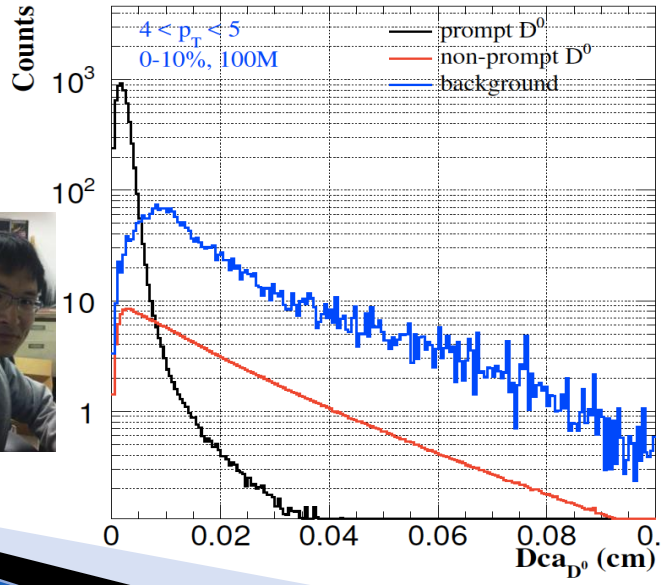


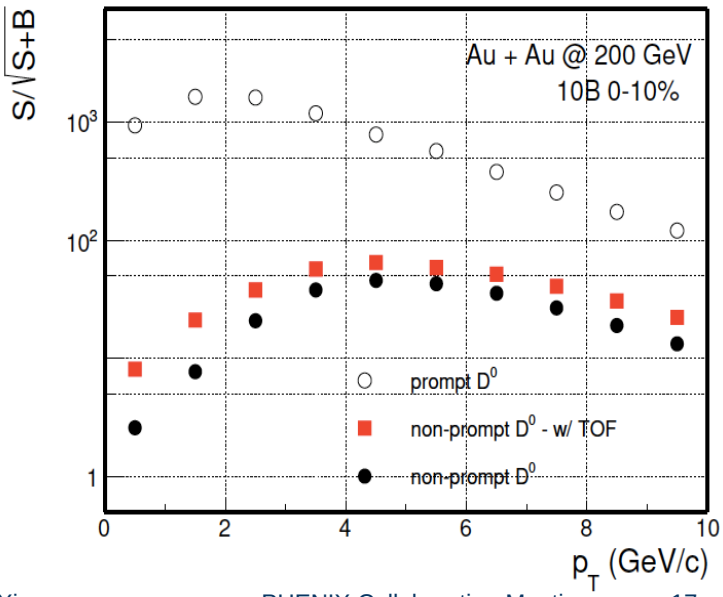
Tagging B-mesons with Non-Prompt D^0



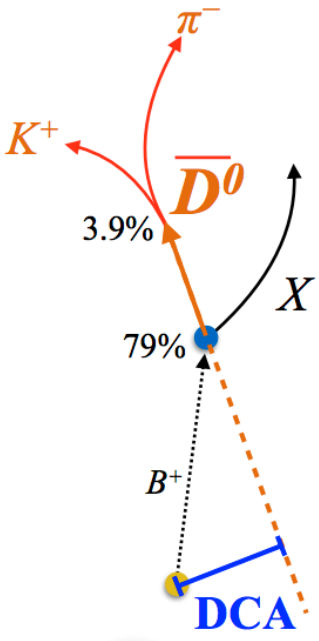
- Impact parameter (DCA) method to tag non-prompt D0 from B-meson decays
- Simulation Single track efficiency and DCA distributions from full Hijing + GEANT simulations
- Setup – Fast simulation with Hijing+GEANT tracking performance
- These fed into a fast Monte Carlo package to generate the distributions for signals (prompt and non-prompt D^0) as well as combinatorial background

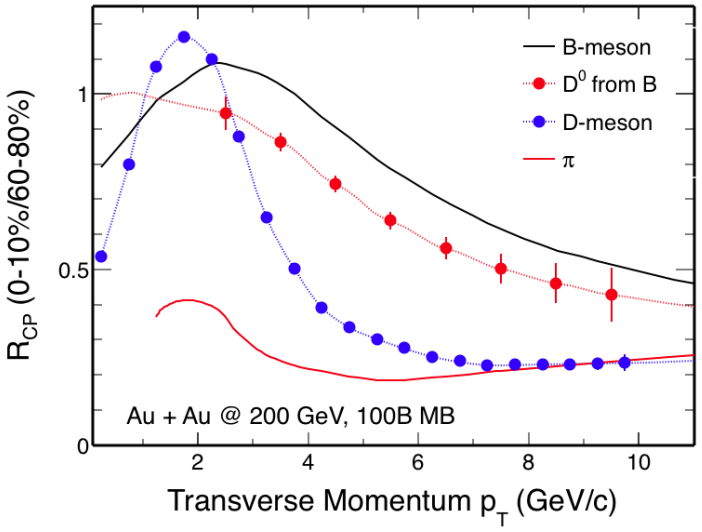


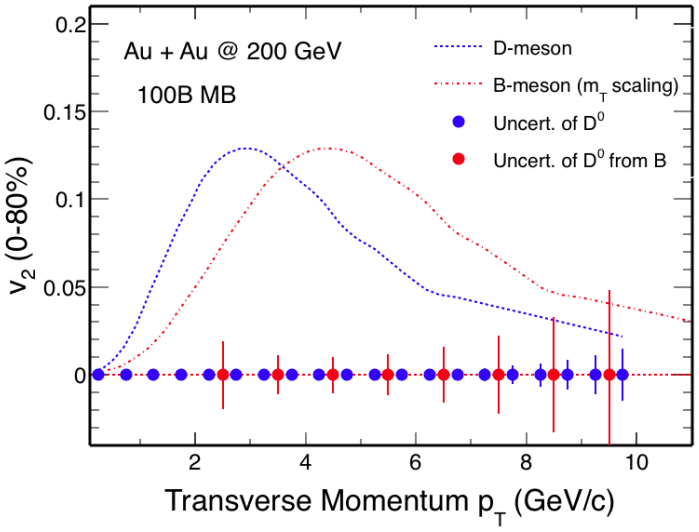


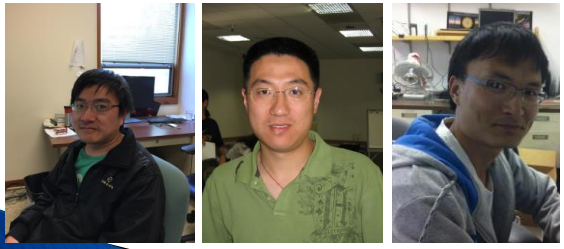


Physics Performance via Non-Prompt D^0





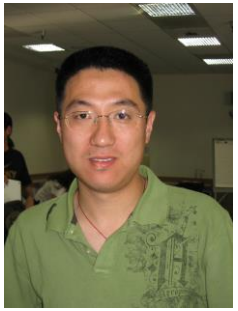




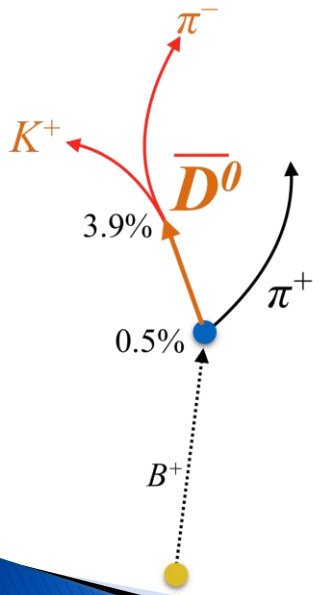
1) Nuclear modification factor R_{CP}(R_{AA}) up to ~10 GeV/c
   - to precisely study the mass hierarchy of parton energy loss

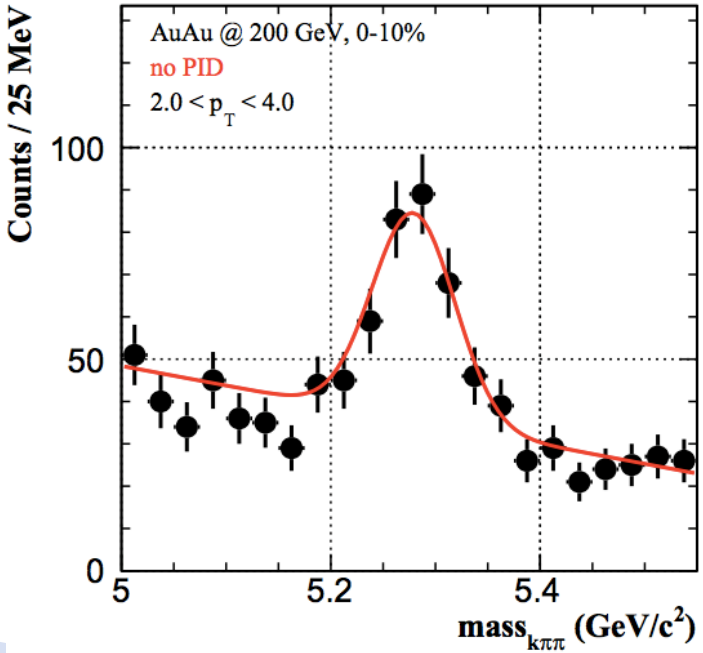
2) Elliptic flow (v_2) up to ~8 GeV
   - to precisely determine the bottom quark collectivity, therefore to constrain diffusion coefficient $\boldsymbol{D_{HQ}}$

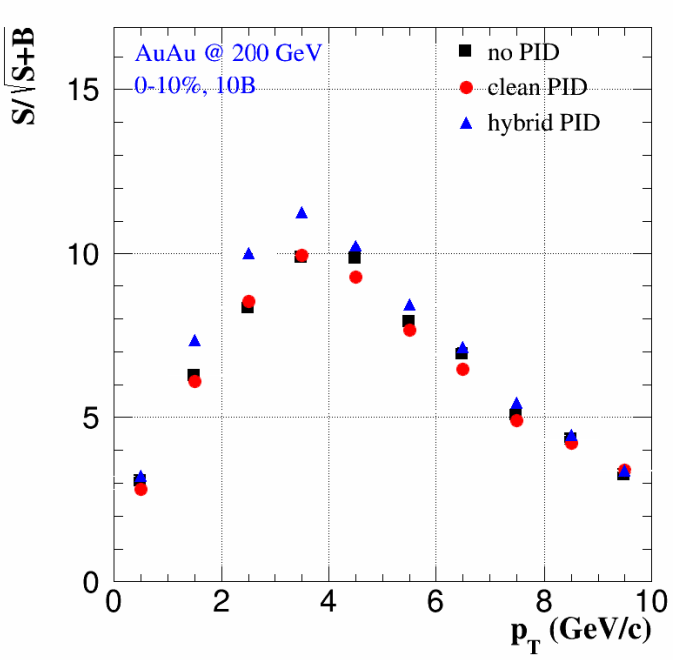
Recent: Exclusive B-meson Reconstruction

- Exclusive B^+ reco with K π π final states
- Topological cuts optimized via TMVA BDT method
- A reasonable measurement of B^+ hadrons via exclusive decay channel in 1-8 GeV/c
- Complementary and systematic control







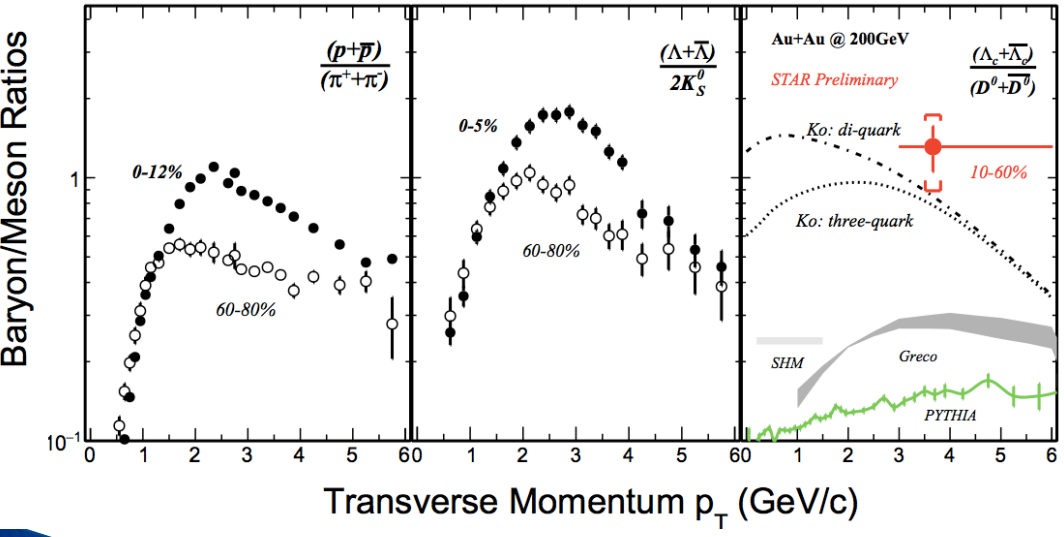
Broader HF meson Physics Program: Λ_c and HQ Correlations

High statistics Λ_c measurements

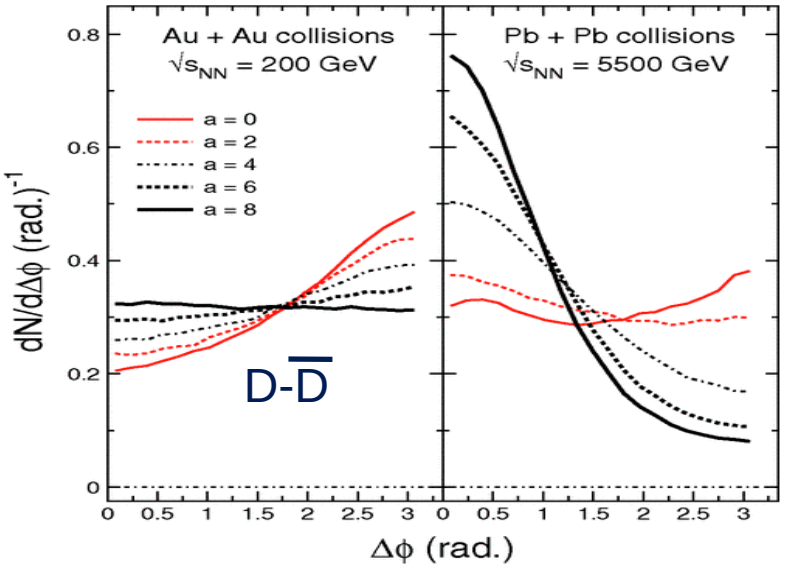
Λ_c/D^0 enhancement sensitive to
- charm quark hadronization, thermalization, domains in sQGP etc.

Heavy quark correlations

- More sensitivity to HQ-medium interaction, thus better determination of ΔE mechanisms and D_{HQ}
- LHC vs. RHIC – different initial pair correlation/medium dynamics



Lee et al, PRL 100 (2008) 222301
Ghosh et al, PRD 90 (2014) 054018
STAR, QM17

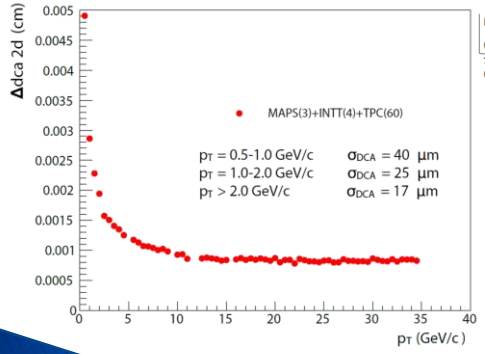


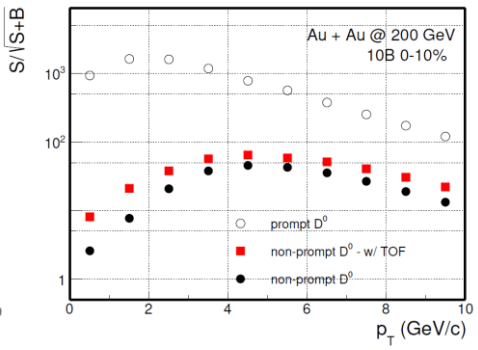
Zhu et al, PRL 100 (2008) 152301

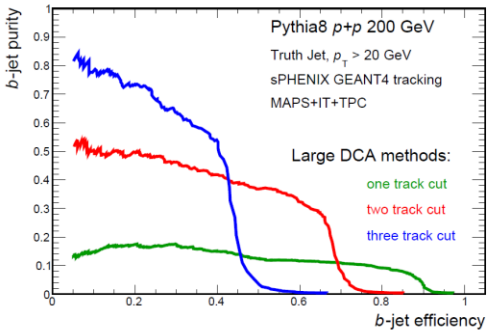
Summary and plans

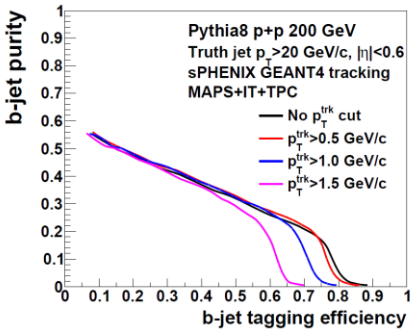
Summary 1: technical performances:

- Realistic implementation in Geant4
  - **Completed**: implement ladder structure in simulation – Tony F., Gaku M.
  - **Completed** : digitization of MAPS detector - Tony F.
  - **On-going:** Update tracking performance plots for MAPS, DCA and dp/p resolutiosn - Tony F.
  - **By summer (?)**: complete the pile-up simulation framework – Mike M., Yorito Y.
- *b*-jet tagging algorithm
  - **By summer, help needed** : Investigating full-detector fast simulation for b-jet simulation. Look into general packages e.g. DELPHES.
  - **On-going, developing:** It will be very useful to use new in-development pattern recognition software to bring back hit collection efficiency.
  - **By summer**: Full calorimetry simulation with secondary vertexing tagger – Sanghoon L.
  - **By summer**: Full calorimetry simulation with high-DCA track counting – Haiwang Y.





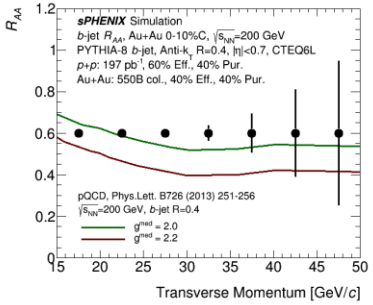


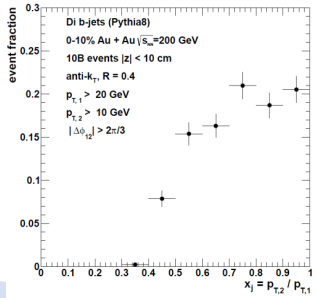


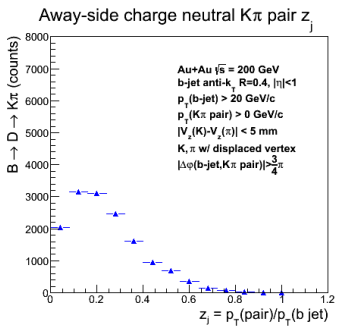
Summary 2: Physics performances

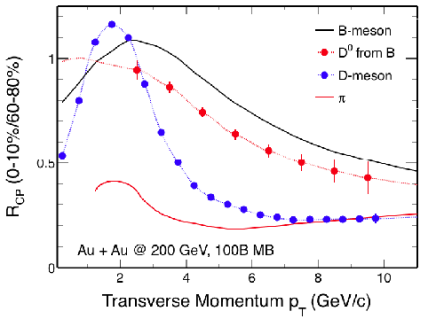
Differential sensitivity of energy loss mechanism and accessing QGP transportation properties

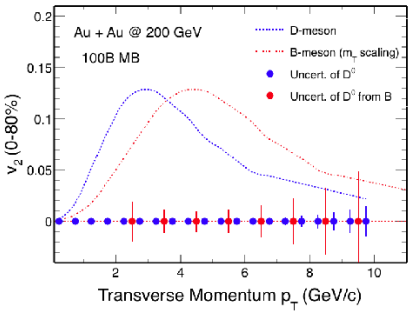
- Update non-prompt D meson performance projection
  - **Completed :** update the Rcp and v2 plot with more realistic simulations for MB and peripheral collisions - Xin D., Xiaolong C.
- Explore complimentary B-hadron channels beyond non-prompt-D
  - **Completed** : exclusive B->D pi - Xin D., Xiaolong C.
  - **By summer, help needed**: B->non-prompt J/Psi->e^+/e^- and p+p triggering
- Inclusive b-jet R_{AA}
  - **On-going, first results:** Update theory curve to RHIC energy – Cesar da S. working with Vitev group
  - **Completed** : Update R_{AA} plot
- di-b-jet asymmetry
  - **On-going:** Extract di-jet purity from Geant4 simulation - Haiwang Y.
  - **Deliverable** : Apply di-jet purity to projection – Darren M., Haiwang Y.
- b-jet-non-prompt-D asymmetry:
  - **On-going:** Produce uncertainty projection in fast simulation – Xuan L.









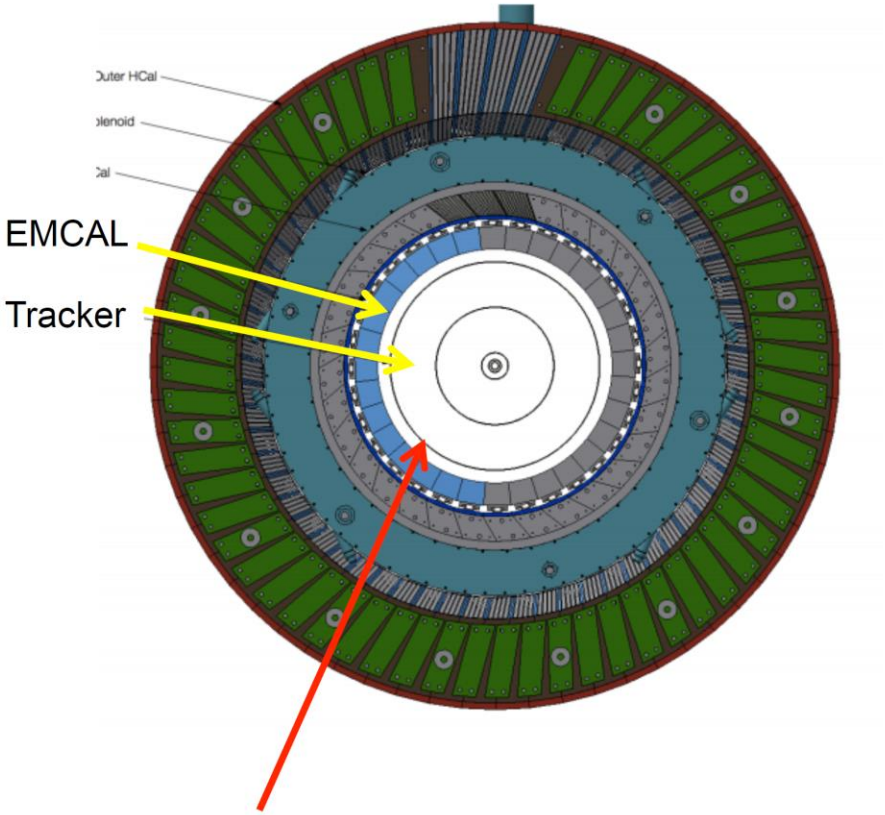


Additional study wish list
Help (always) wanted

- **HF-hadron chemistry**: e.g. high stat. Λ_c, to study HQ hadronization
- **HF-meson correlations**, e.g. D-D_bar azimuthal correlations, to enhance sensitivity to HQ-medium interaction; enhance M/pT ratio scale comparing to D-b-jet correlation.
- Explore **b-jet substructure tools**:
  - Exercise jet-grooming algorithm, FF. – in collaboration with Jet Structure group
  - Tagging gluon splitting via multi-decay vertex in inclusive b-jets.
- Explore **Charmed-quark jet**:
  - charm fragmentation, completes mass hierarchy. Select D meson formed late in formation
  - Try out prompt-D tagger (ALI-PREL-117896) and Corrected Secondary vertex (arXiv:1612.08972). (Sanghoon/Xuan expressed interests)
- Explore **tagged D-meson in correlation with opposite hard structure**
  - Tagging initial c-quark kinematics with correlations, including D-meson - jet correlation and D-meson - photon correlation
  - Study D-FF and formation of D-meson
- Further **b-jet tagging developments**
  - Try different strategy: Soft-lepton tagging
  - Optimize analysis methods: likelihood analysis and machine learning tool
- **Triggering** of B-mesons in p+p collisions
  - B->J/Psi ->e+/e-, EMCal trigger. Exploration work by Sasha L.
  - D meson calorimetry trigger, turn on.
  - Large DCA triggers?

Extra Information

Particle Identification with TOF



10cm gap between TPC and EMCAL - TOF

TOF PID requirement:

$$M = p\sqrt{\left(\frac{ct}{L}\right)^2 - 1}$$

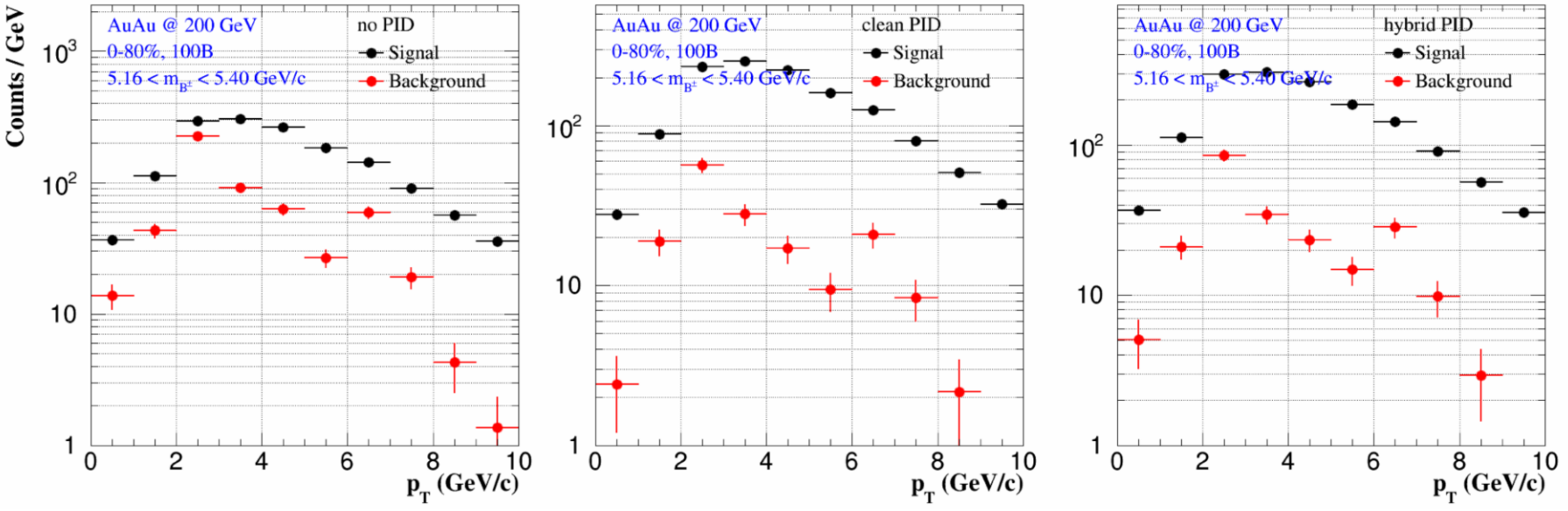
$$\frac{\Delta M}{M} = \frac{\Delta p}{p} \oplus \gamma^2 \left[\frac{\Delta L}{L} \oplus \frac{\Delta t}{t}\right] \sim \gamma^2 \frac{\Delta t}{t}$$

STAR TOF:
Radius ~ 2.15 m, σ_t ~ 65 ps

sPHENIX TOF
(to have the same PID capability)
Radius ~ 0.85 m, σ_t **~ 25 ps**

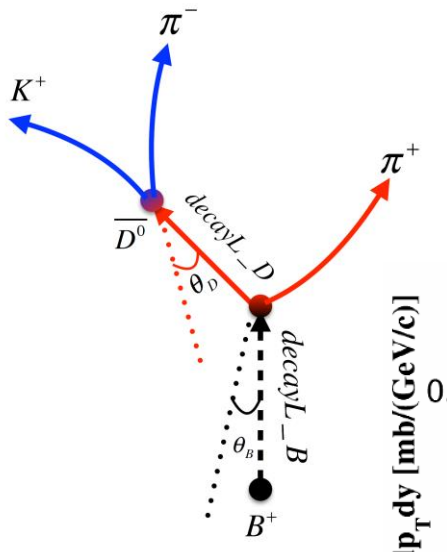
Candidate: Many-gap MRPC

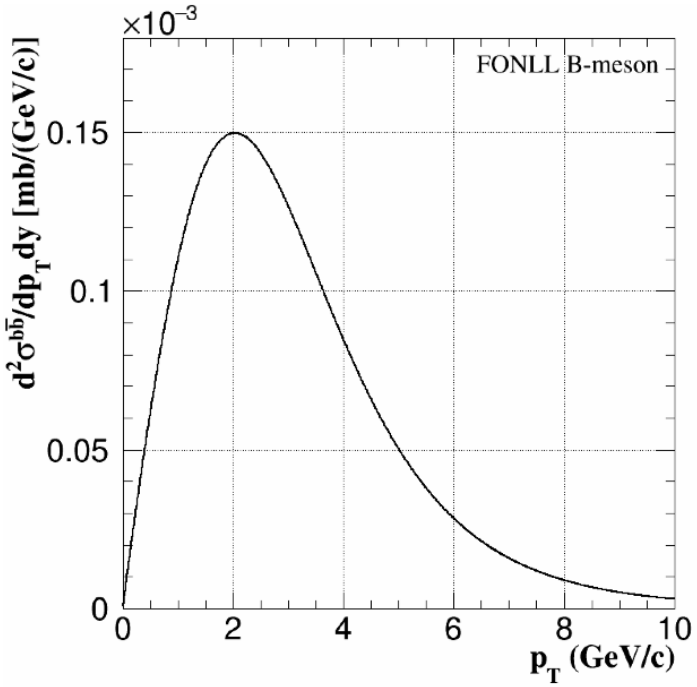
Signal and Bg. pT

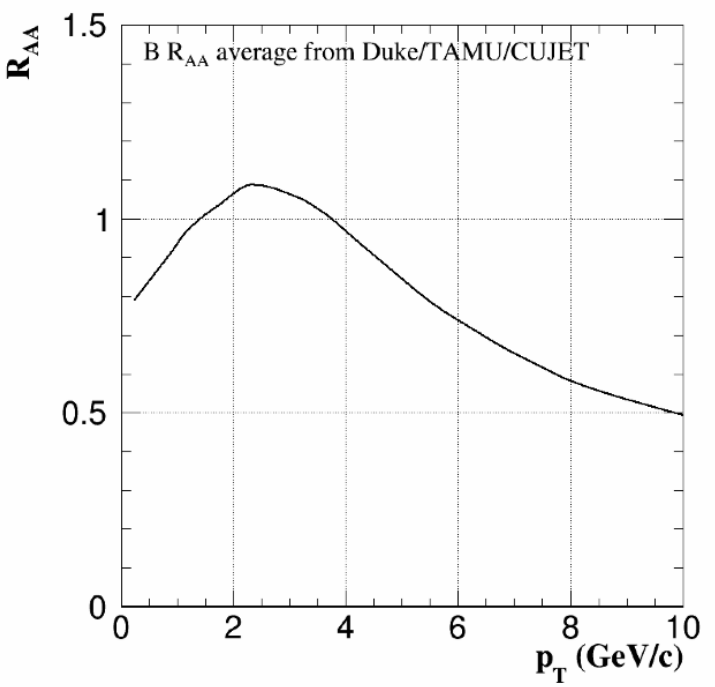


- Hybrid PID: use TOF when TOF is avaliable at pT<1.6
  Clean PID: Must use TOF at pT<1.6
- TOF eff. is from STAR Run14

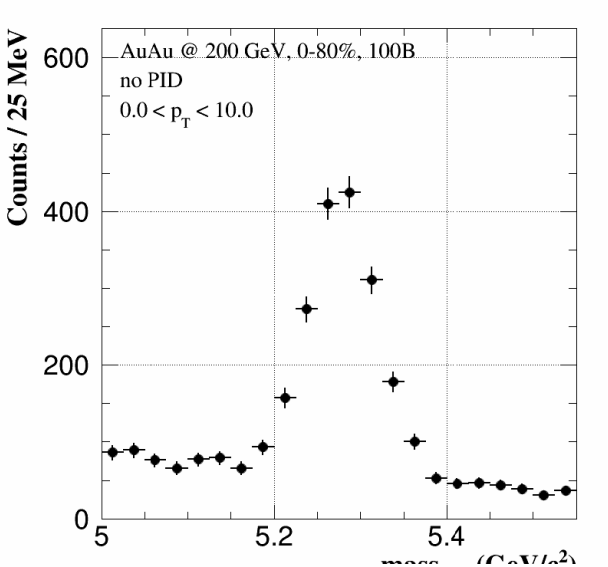
B+, cross section, modification

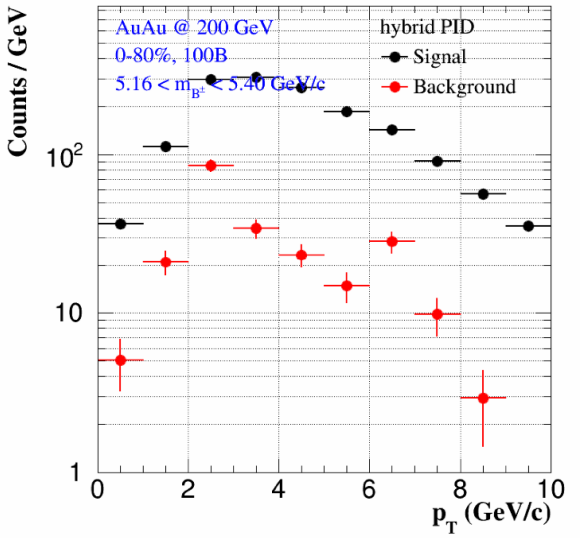


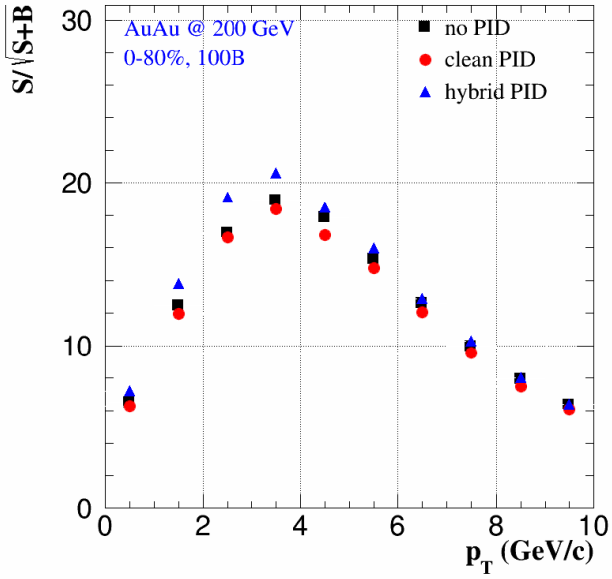


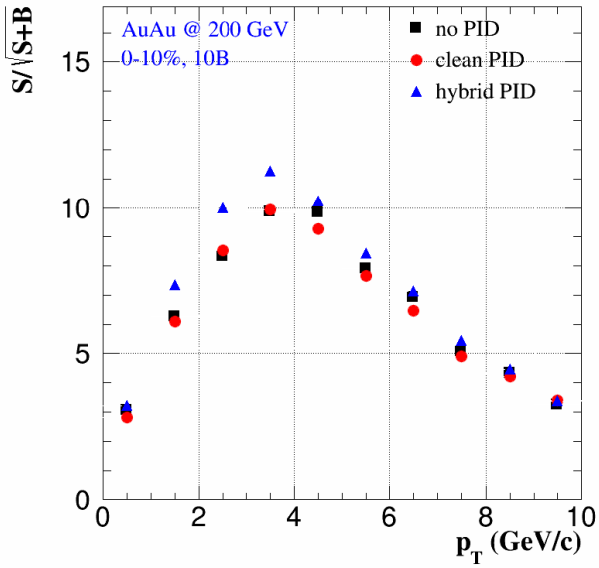


B+ signal to backgroud



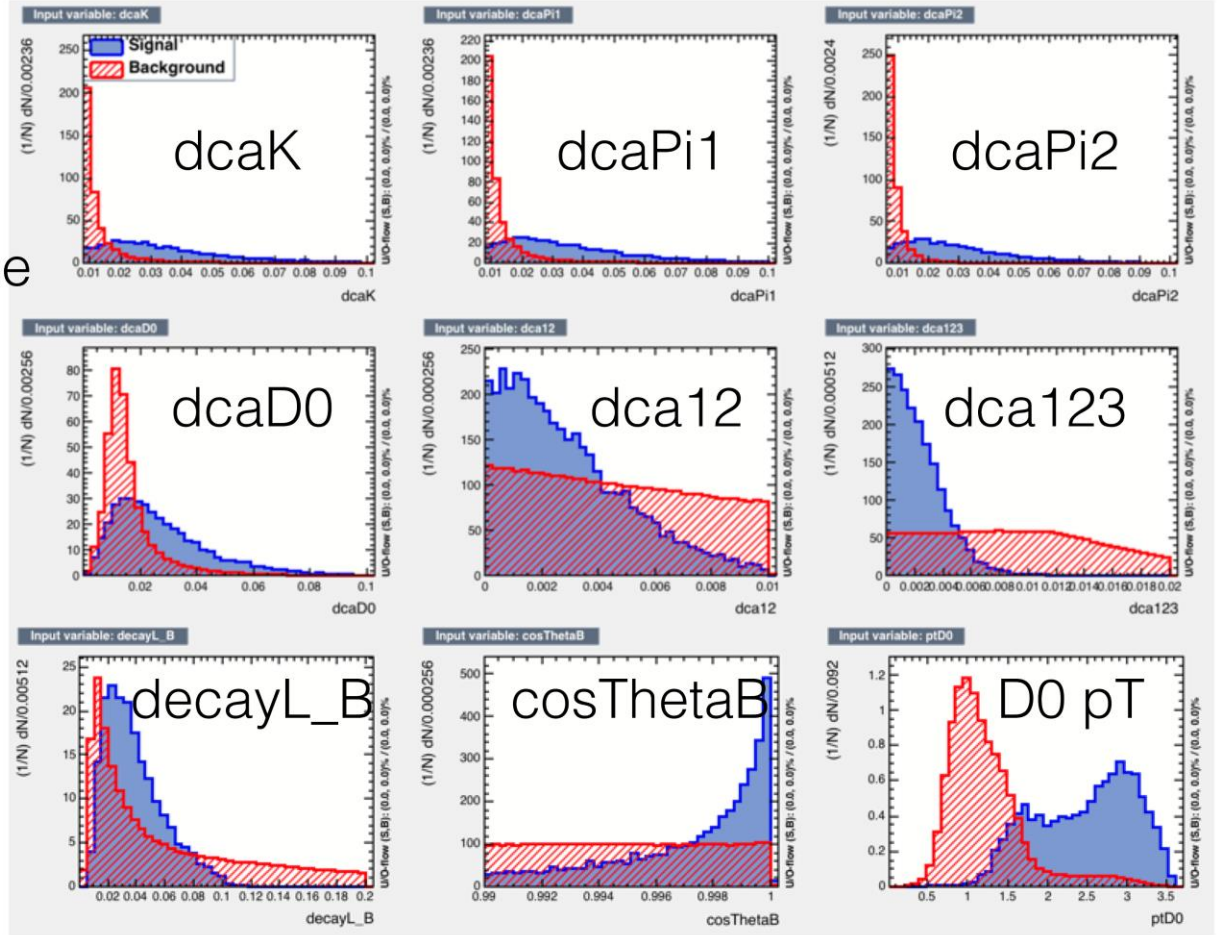






BDT inputs

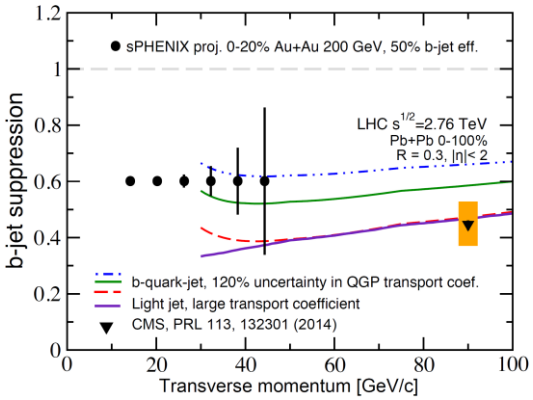
1-2 GeV
no PID case



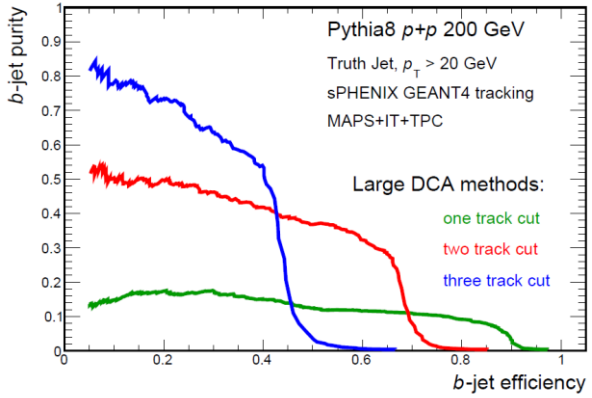
Key dates and events

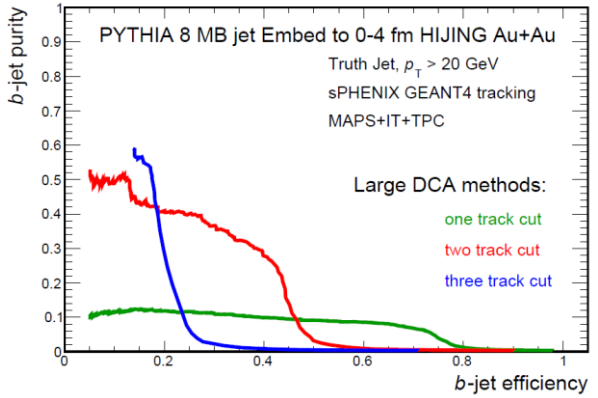
- Soon-ish (in a week): sPHENIX nominal run plan and update all statistical projections. Expect 200B MB Au+Au in 5-year run plan
- End-May: new tracking software (see Haiwang's talk)
- June: submission of analysis notes (next slides)
- Jun 12: pre-collaboration meeting @ BNL ← please attend
  - Encourage HF TG participation in the work-day @ BNL
  - Focusing on using the new tracking software for HF simulations
- Jun 13-14: sPHENIX collaboration meeting @ BNL
- Jun 15-16: RHIC PAC meeting
- Jun 19: sPHENIX-charged MVTX Director's review dry-run (see Ming/Xuan's talk)
- Jul 10-11: sPHENIX MVTX Director's review (see Ming/Xuan's talk)
  - Major review on both science case and detector cost/schedule
- Later summer: MVTX proposal submission to DOE
- Expect DOE review later in 2017 or early 2018

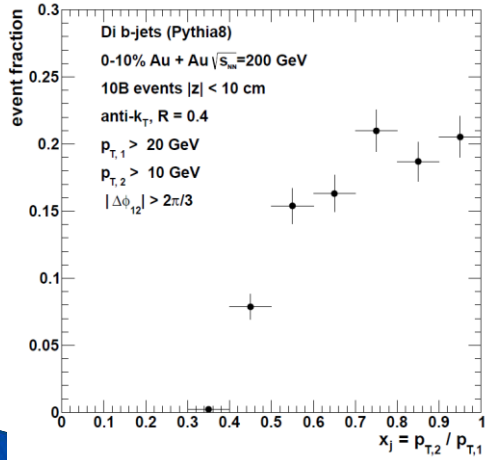
Delivered plots – HF-jet for Feb-2017 MAPS pre-proposal

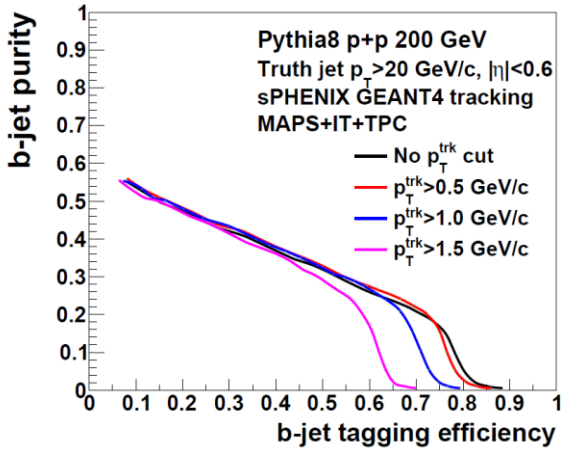


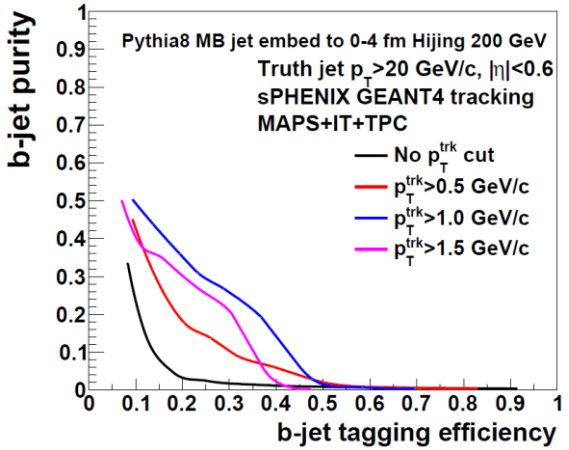
Curve update request, not yet received











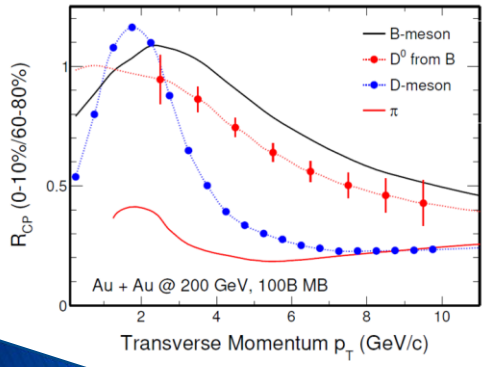
Observable Projections

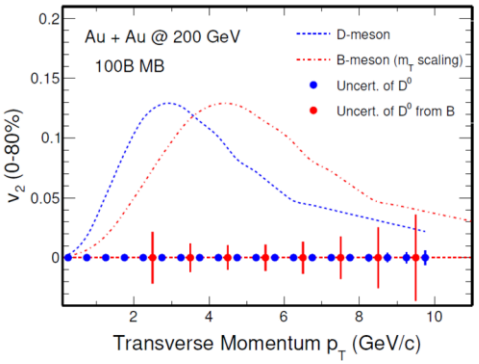
B-jet tagging in p+p

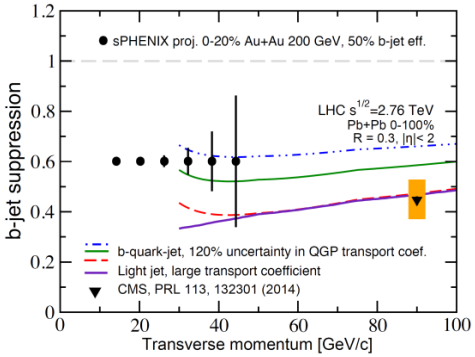
B-jet tagging in 10%C Au+Au

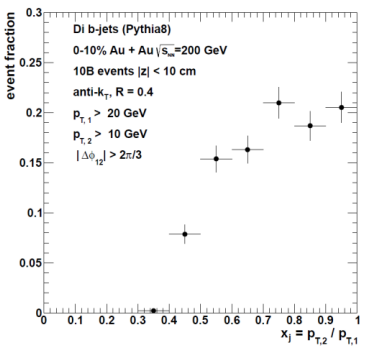
Path forward: summary

- Apr review/preproposal: Solidifying results and studies started preparing for thesFeb-2017 pre-proposal
- Summer review/full proposal:
  - Expansion of selected topics: more realistic simulation, exclusive B-meson reconstruction
  - Addressing BNL-charged review comments
  - Many more HF capabilities need your help to develop
- Expect workfest around time of May collaboration meeting





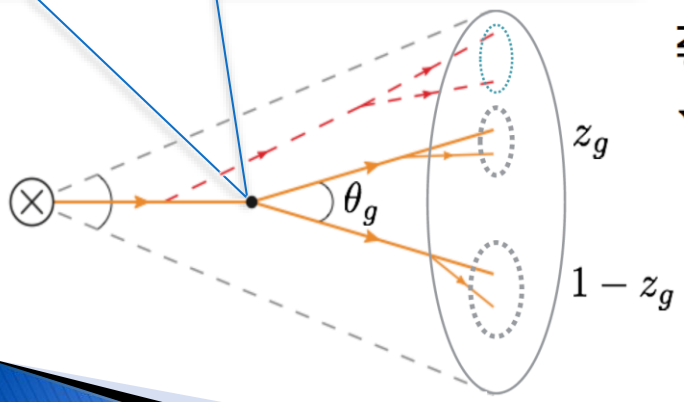




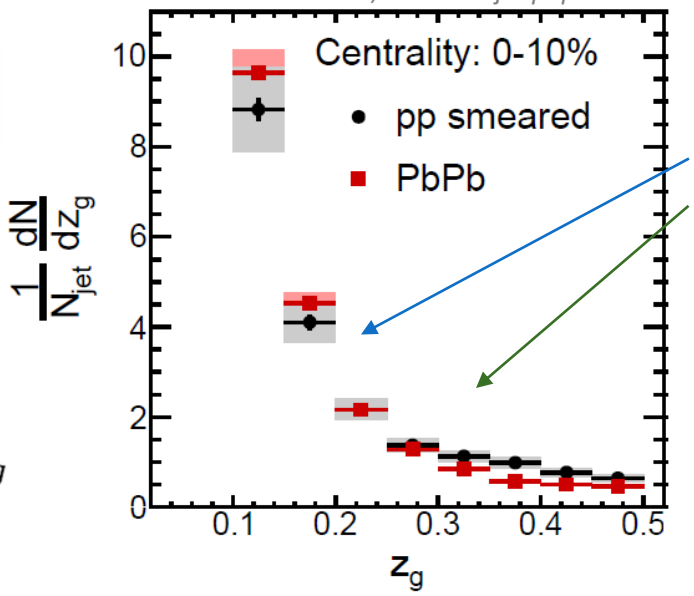
More ideas on *b*-quark jet selection? Jet structure tools

- Jet structure tool developed in HEP adapted in HI field
- Jet grooming observable z_g to separate *b*-quark jet and $g/q \rightarrow b\bar{b}$ jet?
- Mid-term goals: in collaborate with JS TG in developing grooming tools – volunteer welcomed!

Earliest splitting:
More symmetric for $g/q \rightarrow b\bar{b}$ jet?



CMS-PAS-HIN-16-006, inclusive jet *p*+*p* 5.02 TeV

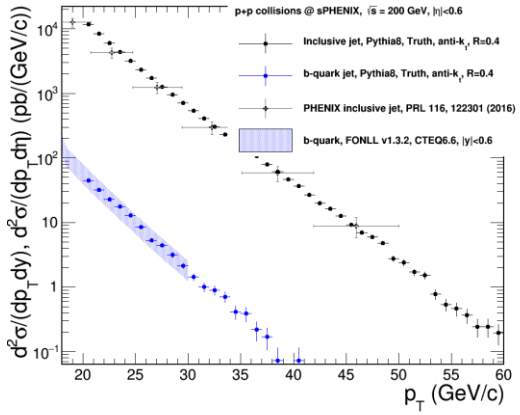


- *b*-quark jets ??
- $g/q \rightarrow b\bar{b}$ jet ??

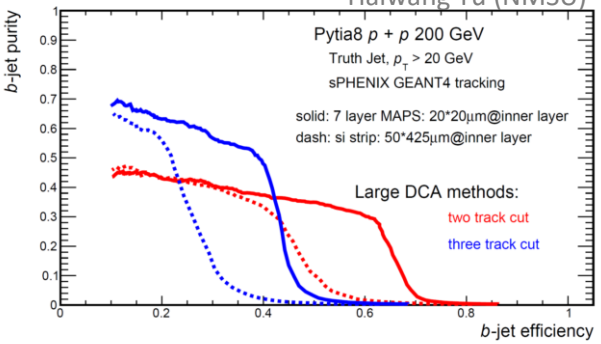
A+A Modification would enhance z_g~0.5 (i.e. $g/q \rightarrow b\bar{b}$ less suppressed)?

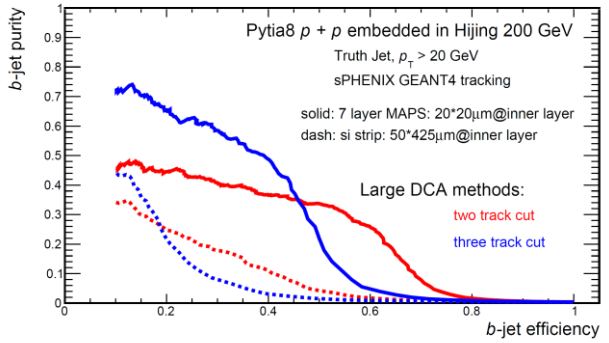
Detector requirement on MAPS/MVTX

- Caveats: there are trade-offs between tail/efficiency/DCA. Important final check is b-jet tagging performance working point: reaching 40% efficiency and 40% purity.
- Low fake high-DCA tail background
  - *b*-jets are rare (0.1%-1%) object identified via displaced vertex, therefore sensitive to rare large-DCA fake track background.
  - The working point of B-jet tagger is few-sigma above DCA peak, and
  - Possible specification: true large DCA track/fake large DCA track > 1:1-1:few for DCA tail integrated from 2-sigma to 1mm
- Tracking efficiency
  - Efficiency for multi-track tagging algorithm is sensitive to (tracking efficiency)^N
  - Possible specification: Require 60% (HFT KPP) – 75% (HFT UPP) single track efficiency p_T>1 GeV/c
- DCA
  - B-jet DCA requirement is relatively moderate
  - Requirement: DCA<100 um @ p_T>4 GeV/c (sPHENIX proposal)
- DAQ output event rate
  - Statistical limited measurement
  - B-jets are jet-structure study based on inclusive jets, require large jet-sample rate
  - Requirement: 15 kHz trigger rate to match sPHENIX DAQ



Haiwang Yu (NMSU)

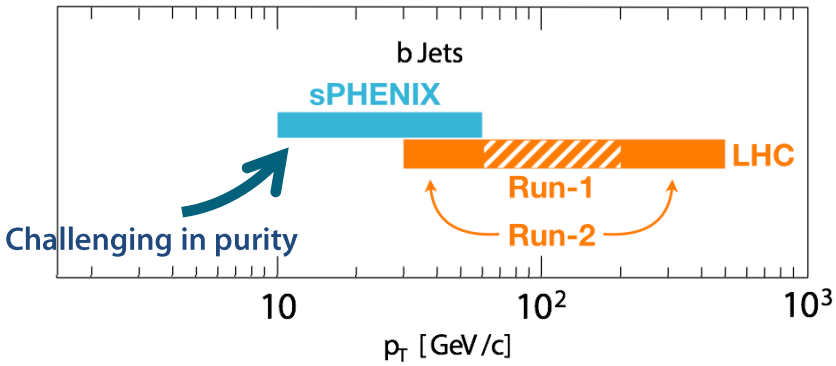




Jin & Xin

Jet finding and fake rejections

- HF-jet are based on jet, relying on jet finding development lead by JS TG
  - Emphasis on purity and reach to lowest-possible-p_T jet, where mass effect is maximized
  - No statistics for *b*-jet beyond $p_T > 50$ GeV/c
- HF-jet specific: response in detector for *b*-favored jet, unfolding and media modification
  - Require join study with JS TG in term of experience and toolkit developments



sPHENIX scientific proposal